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CHARLES D. WALCOTT, DIRECTOR

GEOLOGY

OF THE

ASPEN MINING DISTRICT, COLORADO

WITH ATLAS

BY

JOSIAH EDWARD SPURR

SAMUEL FRANKLIN EMMONS, GEOLOGIST IN CHARGE

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CONTENTS.

ILLUSTRATIONS.

ATLAS SHEETS.

LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, June 30, 1896.

Sir: I have the honor to transmit herewith the manuscript of the text and drawings for the illustrations and atlas of a report on the Geology of the Aspen Mining District of Colorado, by Mr. Josiah Edward Spurr, and to request that it be printed as one of the monographs of the Survey.

Very respectfully, your obedient servant,

S. F. Emmons, *Geologist in Charge.*

Hon. Charles. D. Walcott,
Director United States Geological Survey.

PREFACE.

Field work in the Aspen district was begun by the writer and Mr. Tower about July 1, 1895, and continued to about December 1 of the same year. The summer months were chiefly spent in the study of the surface, while the fall and early winter were devoted to the investigation of underground phenomena, as shown in mine workings.

At the beginning of the work the first reconnaissance showed that the structure of the district was peculiarly complicated, and it was recognized that in order to finish the investigation within a reasonable period of time the methods of work must be modified in proportion to the degree of complication. Work was begun in the most complicated district—that represented in the northern part of the Tourtelotte Park special map (Atlas Sheet XII). Here at first a system of cross-sectioning at intervals of a few hundred feet was tried, but it was found that the complication was such that no accurate results could be obtained. The system was then adopted of examining the whole ground thoroughly by following continuously formation and fault lines where these outcropped, and locating accurately every place where bed rock could be found. These results were plotted together on a topographical map as a record of fact to which all final solutions must conform, and a preliminary complete working map, which filled out by inference and estimation what the record of fact did not furnish, was constructed. This being finished, special maps covering the important mining districts were constructed on a much larger scale. In these districts the mines were carefully gone through, the mine maps obtained, reduced to a common scale, and plotted together on the topographical maps. When all the data which could be obtained from this underground work had been collected, they were combined with the information already obtained from the surface, and maps on the 300-foot scale were constructed, the details being worked out by a system of cross-sectioning preliminary to the final

areal mapping. From these smaller maps the structure was worked out by degrees into the larger maps which inclosed them; and when all possible information had been assembled, final maps were constructed, which, however, differed from the preliminary ones only in detail.

The winter months were spent in working out more carefully the structure of the region, and in microscopic and comparative study of the rocks and ores. In the spring of 1896 the writer was unexpectedly requested to proceed to Alaska, and it became necessary to write this report in a somewhat hurried manner. It was not practicable, therefore, to devote much care to the writing, and the report is by no means so complete as it was originally intended to make it. Many things have been lightly passed over, or even omitted altogether, which might profitably have been worked out more elaborately. It is hoped, however, that the report may be of some use to the mining population, for whom it is chiefly intended, and that from a scientific point of view it may also possess some value.

During all the field and office work on the Aspen district the writer has been ably seconded by Mr. George Warren Tower, to whose ability and energy much of the credit of accomplishing such a large amount of work in so short a time is due.

In conclusion, thanks should be offered to the people of Aspen, who, with scarcely a single exception, have done everything in their power toward facilitating the work. To Mr. D W. Brunton and Mr. D. Rohlfing especial acknowledgments are due, but to name all the gentlemen from whom favors have been received would simply be to furnish a list of prominent mining men in Aspen; nor should the common miner and prospector be omitted, whose ready courtesy and hospitality will long be a pleasant remembrance.

JOSIAH EDWARD SPURR.

WASHINGTON, *May 20, 1896.*

INTRODUCTION.

By S. F. Emmons.

POSITION.

Aspen is one of the most picturesquely situated mining towns of the Rocky Mountain region. It lies in the valley of the Roaring Fork River, at a point where that stream issues from the area of granite and gneiss which constitutes the uplift of the Sawatch Mountains into the upturned Paleozoic and Mesozoic strata that encircle it. The Roaring Fork heads in the Sawatch Mountains, on the west side of the main crest and about opposite the Twin Lakes of the Arkansas Valley. Its general course is northwest, and below Aspen it flows along the eastern flank of the Elk Mountain uplift for about 50 miles to its junction with Grand River at Glenwood Springs. The scenery along this stream above Aspen is very sharply contrasted with that below, and in both regions is largely dependent upon the geological structure. Above is a relatively broad and straight valley, lying between rounded and generally rather barren-looking hills of granite and gneiss, bare of vegetation and forbidding of aspect. At Aspen the character of the scenery changes; the hills are well covered with vegetation, and are remarkably steep and rugged in topographical form; the valley bottom is now broader and is filled up, to a certain extent, with horizontally bedded gravel deposits, which form a nearly level plain, admirably adapted for the location of a town.

As has already been remarked,[1] the scenery and topographical forms of the Elk Mountain region are characterized by a peculiarly alpine aspect, in strong contrast to those of the eastern flanks of the Rocky Mountains. This is due in part to the greater rainfall on the western slopes, and in part

[1] Geologic Atlas U. S., folio 9, Anthracite-Crested Butte, Colorado, 1894.

to the underlying geological structure of the region. The valleys are generally narrower and deeper, the mountains more rugged and precipitous, and the surface of both is more luxuriantly covered with forest and plant growth.

The most striking and characteristic feature of the scenery at Aspen is the narrow spur or ridge to the west of the town, lying between the valleys of the Roaring Fork and Castle Creek, which is generally known as Aspen Mountain. The northern portion of the spur to which this name is applied rises from the valley flat on which the town is situated in a slope whose steepness is exceeded only by that of the western slope of the same spur toward Castle Creek. How steep either slope must be will appear when one considers that the base of the mountain is only from a mile to a mile and a half wide, while its crest is 2,000 to 3,000 feet above the valleys that lie at the base on either side. As seen from the town, this ridge appears to have three summits, to which the names Aspen, West Aspen, and East Aspen mountains have been given, the first being the main crest of the spur, West Aspen Mountain its rugged northern point, and East Aspen Mountain the more rounded portion of the spur, stretching northeastward at the gateway of the Roaring Fork Valley, where the river issues from the granite region of the Sawatch.

East of the town, between Roaring Fork and Hunter Creek, rises the steep but rounded spur called Smuggler Mountain, named from the mine that was early opened upon it, while northward, forming the eastern wall of the lower part of the valley, is the long, flat-topped spur called Red Mountain.

From the following report it will be seen that the great mineral wealth of this region is found in a narrow belt of Paleozoic rocks, which are steeply upturned against the granite and broken in the most complicated manner by a network of faults; that it is along these faults, and proceeding from them outward where they traverse calcareous and dolomitic beds, that the principal ore deposition has taken place; and that this faulting, which commenced with the earliest folding of the sedimentary rocks and has continued to a certain extent to the present day, has been most intense and long continued on the ridge known as Aspen Mountain, which is so striking to the eye by reason of its peculiar form, and which, as the present investigation has shown, presents evidence of dynamic disturbance greater than that of any

area of similar size yet observed in the State, not excepting even the remarkable region of the Leadville mines.

If one examines a general geological map of Colorado it will be noted that at just this point the strike of the Paleozoic rocks resting upon the Sawatch granite changes abruptly from a little west of north to northeast. The geological significance of this change of strike is that here is the point where the two converging uplifts of the Sawatch and the younger Elk Mountains come together, and that, whereas north of this point there was room for the sedimentary beds included between them to be compressed into broad anticlines and synclines, here they came so close together that there was no room for the development of more than embryonic folds, and the rock strata were crushed, squeezed, and broken into narrow blocks or sheets by a complicated system of faults.

DISCOVERY.

Though it is doubtful whether the early prospectors possessed a sufficiently broad geological knowledge to have observed the above facts, it is tolerably certain that those who first came here in 1879, men who had been working in Leadville, had observed on the maps of the Geological Atlas of Colorado that the Paleozoic rocks that carry the silver at Leadville nearly encircle the Sawatch uplift, and that, with the keen observation that characterizes men of their profession, they selected limestone beds of the same horizon as the ore-bearing zone at Leadville in which to make their investigations.

In the summer of 1879 the Durant, Iron, Spar, Monarch, Late Acquisition, and Smuggler claims were located. During the winter work was suspended, in great measure because of the Indian revolt on the neighboring Ute reservation. In the spring of 1880, however, the Emma, Aspen, Vallejo, Mollie Gibson, Argentum-Juniata, Della S., J. C. Johnson, Park-Regent, and other claims were located. The town, which had at first been called "Ute," was rechristened Aspen, probably from the abundance of that tree on the neighboring hills. Explorations continued along the strike of the limestone belt, and claims were located along it for a distance of 30 to 45 miles, reaching the valley of the Frying Pan on the northeast and that of Taylor River on the south. Ashcroft, at the head of Castle Creek, was at first the most important mining town, but although the geological indications around it are most promising, but few considerable bodies of rich ore

have been discovered in that region, the only mines now producing being the Express mine, at the Leadville horizon, and the Montezuma group on Castle Peak, in the Maroon formation and diorite, at about 13,500 feet above sea level. The richer deposits near Aspen itself made but little show upon the surface. On Smuggler Mountain and along the base of Aspen Mountain their outcrops are buried beneath glacial gravels; moreover, the ore contains much less iron and manganese than the Leadville deposits, and hence the outcrops of the ore bodies are not so readily distinguishable from ordinary altered limestone or dolomite.

Thus in 1881 and 1882 the prospects on the Castle Creek slope of Aspen Mountain were considered the more promising, and it was not until 1884 that the existence of the very rich ore bodies on Spar Ridge was disclosed by the workings of the Emma and Aspen mines. As a result of the excitement consequent upon these discoveries, the town of Ashcroft was moved almost bodily to Aspen, many houses having been dragged over the 12 miles that separate the two towns.

DEVELOPMENT.

For the first six years of its existence the great drawback to the development of the district was its inaccessibility. It could be reached from existing railroads only by crossing the summits of lofty ranges of mountains. The shortest and most generally traveled line of approach from the east left the railroad at Granite, 15 miles below Leadville, in the valley of the Arkansas, and ascending the Lake Fork, passed Twin Lakes, crossed the summit of the Sawatch by Hunter Pass, and descended to Independence and thence down the Roaring Fork to Aspen, a distance of about 40 miles. A second route, 72 miles in length, leaving the railroad at Buena Vista, lower down the Arkansas Valley, crossed the Sawatch by Cottonwood Pass or Chalk Creek Pass, each about 11,000 feet high, into the valley of Taylor River, and ascending that, crossed Taylor Pass to Ashcroft, and thence followed down Castle Creek to Aspen.

The first shipment of ore from Aspen came from the Spar and Chloride mines on Aspen Mountain; the ore was transported on the backs of burros or jackasses to Granite or Leadville to be smelted. The cost of such transportation was at first from $50 to $100 per ton, but as competition increased these rates were reduced, near the time of advent of the railroads, to $25 per ton.

In 1886 the Colorado Midland Railroad, which had built its line from Colorado Springs to Leadville in order to get part of the profitable ore-carrying business of the latter place, was induced by the promising developments of ore at Aspen to project a line to that point. This work had hardly been undertaken when the Denver and Rio Grande Railroad Company, whose line was already built down the Eagle River to Red Cliff, felt obliged to enter into competition for the Aspen trade, and a railroad-building contest ensued, each striving to reach the objective point first. The line of the Colorado Midland, which was a broad-gauge road, ascended the Sawatch Range directly opposite Leadville, passing through its crest by a tunnel at Hagerman Pass, and descending Frying Pan Creek to the Roaring Fork. The route of the Denver and Rio Grande Railroad was longer, but it was then a narrow-gauge line, and it followed valleys all the way, descending the Eagle and Grand rivers to Glenwood Springs, and thence ascending the valley of the Roaring Fork. In spite of the difficult engineering and the many tunnels in the magnificent canyon of Grand River above Glenwood, the Denver and Rio Grande reached Aspen first, in October, 1887, while the trains of the Colorado Midland did not actually reach the town limits until February, 1888. By the advent of the railroads the expense of transportation of ore to the smelters at Leadville, Pueblo, or Denver, was reduced to $10 or $15 per ton, and in later years, under special circumstances, this rate has been reduced as low as $5 per ton, the charges being in a measure proportioned to the value of the ore, thus favoring, in the interest of all concerned, the working of ores of lower grade than would otherwise be possible.

LITIGATION.

Another cause besides the difficulty of transportation that has retarded the development of the Aspen mines has been the many lawsuits in regard to the ownership of the most valuable ore bodies that have sprung up as a natural conseqence of the peculiar unfitness of the United States mining laws for giving a clear title, or even any title at all, to deposits of this nature.

It is not the province of employees of this Survey to discuss the merits or demerits of rival claims to mining property under survey; indeed, as they often enter properties in regard to which suits are pending, it is their

practice to avoid any knowledge of the points at issue, at least until their examinations are completed and their conclusions reached, in order that their opinions may be drawn solely from the facts of nature, with no possible bias from such litigation.

The suits in regard to Aspen mines, however, have been notorious as showing the relative advantages and disadvantages of the two methods of giving title to mining claims—i. e., according to what may be called the law of the apex, which is peculiar to the United States, or according to square locations, or vertical side-line boundaries, which is the practice in regard to all other land titles, and the method of granting mining titles that obtains among all other nations which have important mining industries. At the request of the writer Mr. D. W. Brunton, a leading mining engineer of Aspen, who has taken active part in most of the suits, has furnished the following brief statement of the points at issue in the more important mining suits at Aspen, and of the manner in which the disputes have respectively been decided.

MINING SUITS.

In November, 1883, the Spar mine, situated on the crest of what is known as Spar Ridge, on Aspen Mountain, had followed the contact between the blue limestone and the brown dolomite to and into the Washington No. 2, a mining claim lying immediately west of the Spar, and had uncovered considerable ore bodies in the Washington No. 2 claim. The Washington claimants were then engaged in mining ore within their surface boundaries, and the owners of the Spar brought an injunction suit in the circuit court of the United States at Denver to restrain the Washington claimants from mining ores within the end lines extended westerly of the Spar claim. The contention of the Spar claimants was, in substance, that they owned the apex or outcrop of a contact vein lying between the blue and brown limestones, which vein, on its dip and downward course into the earth, extended beyond the westerly side line of the Spar and into the territory of the Washington No. 2 claim. This contention was denied by the Washington No. 2 owners, who claimed that the ores of Aspen Mountain, or at least those included within the Washington No. 2 claim, did not occur in any true lode or vein, but that the same occurred in segregated masses, pockets, and impregnations, fortuitously distributed through the limestones forming the mass of the mountain, and that, therefore, the same did not come within the purview of the statute permitting the owner of the apex or outcrop of the vein to follow the same on its dip beyond his vertical side lines and into the territory of adjoining claimants. This was the original apex suit in Aspen, and was settled, in a few months and before any trial upon the merits was had, by the owners of the Spar purchasing the Washington No. 2 claim.

The Durant mining claim lies immediately south of the Spar claim, and in 1884 its owners started an incline upon the contact between the blue and brown limestones, directing the same toward the rich ore bodies discovered about that time in the Emma and Aspen claims, which claims lay from 300 to 500 feet west of the Durant claim. In the winter of 1884 and spring of 1885 the Durant claimants instituted injunction proceedings, followed by ejectment suits, claiming all the ores within the end lines of the Durant claim extended westerly, by reason of the alleged existence of the apex of the vein containing these ores within the Durant mining claim. The substantial result of these injunction proceedings was to prevent the production of ores from the richest mines on Aspen Mountain pending the determination of these suits, which were four or five in number. The defendants in the various suits denied the existence of any vein or lode of ore in Aspen Mountain within the meaning of the statutes governing extralateral rights, and alleged that the ore bodies consisted of segregated masses, pockets, and impregnations, occurring sometimes in the blue limestone or calcite, sometimes in the brown limestone or dolomite, and sometimes at or near the contact between these two formations. It was also claimed that the limestone strata containing the ores of Aspen Mountain were synclinal, the east crest or Spar Ridge forming one edge or outcrop, and the other outcropping on what is known as West Aspen Mountain. It was further demonstrated that rich ores occurred in various places at or near the surface of the blue limestone strata throughout this synclinal area, and that these were sometimes connected by ore-bearing faults or fissures with the main ore bodies of the mountain. They also denied the continuity of the so-called apex or outcrop throughout the length of the Durant claim. These cases were bitterly contested, vast amounts of money being spent in the employment of counsel, and still larger amounts in development work made by each party, looking to the establishment of its favorite theory. The first and only case to come to trial upon the merits was that of the Durant against the Emma, which was tried in December, 1886, occupying some three weeks in the United States circuit court at Denver. The result was a verdict in favor of the apex claimants. The so-called side-line claimants, the defendants in this suit, immediately paid up the costs under the statutes of Colorado, and were awarded a new trial, and at once instituted a more vigorous policy of development for the purpose of refuting the position of the apex claimants, and during the year 1887 large amounts of money were expended by both sides in preparing for the next contest. The side-line claimants, among which were the owners of the Washington No. 2, Emma, Vallejo, Aspen, Aspen Mammoth, and other claims, contributed to a common pool, known as the side-line defense fund, for the purpose of defeating the apex claims.

In 1888, before any further trials were had, a settlement was effected between the owners of the apex and side-line claims, the substance of which was that the side-line claimants deeded one-half of the ores contained within their surface boundaries to the apex claimants, the apex claimants, on the other hand,

releasing to the various side-line claimants one-half of the ores contained within the surface boundaries extended downward vertically of such side-line claims.

Throughout this litigation the ablest mining lawyers in Colorado were engaged on one side or the other of the controversy and the best mining experts and geologists of the country were employed to formulate theories and direct the developments on behalf of each side. It is conservatively estimated that the cost of the litigation up to the time of settlement, including attorneys' fees, expert witnesses, and development made for the purpose of these suits, and which was useless for any other purpose, was more than the sum of $1,000,000.

Next in importance came the litigation on Smuggler Mountain between the Standard Mining Company, of Kansas City, as owners of the J. C. Johnson and Chatfield claims, against the Della S. Mining Company, the latter company owning a number of claims lying westerly from and below the J. C. Johnson and Chatfield. This contention began in the latter part of 1890 and ended in February, 1892, and involved the ownership of exceedingly large and valuable ore bodies on Smuggler Mountain. The theories of the contending parties are well stated by Judge Hallett in his charge to the jury, from which the following extracts are taken:

PLAINTIFF'S POSITION.

The position of the plaintiff in this instance is that the locations to which they have established titles, the J. C. Johnson and the Chatfield, have within their limits the apex of the vein which, in its descent into the earth and through the side lines of these locations, extends into that adjoining, which is owned by the defendant. So that by virture of the ownership of the top or apex, under this statute, they are entitled to claim the lode from the top of the ground extending into the territory adjoining.

* * * * * * *

THEORY OF THE DEFENSE.

The theory of the defense is that, after the vein was deposited in this fissure or opening from the top of the mountain downward, there came a fault which broke off the lower part from the upper and removed the upper part some distance easterly, something over 200 feet easterly, so as to entirely dissever and disconnect them in such a way that the ownership of one can not be said to be the ownership of the other. In this there are two propositions: One that the fault occurred, and the other that the vein was deposited before that fault occurred. * * *

The trial occupied ten days, the jury returning a verdict in favor of the Della S. Mining Company, thus in effect finding that the vein which has its apex in the J. C. Johnson claim had been faulted subsequent to the deposition of the ore bodies, and that the J. C. Johnson vein ceased at the eastern edge of the fault plane, and that the Della S. vein, commencing at the western side or edge of the fault plane, constituted a separate and independent vein within the Della S. territory. Within a few days after the trial the case was settled, the entire property passing to the Della S. Consolidated Mining Company.

Spar Ridge, upon which occur the so-called apexes of the Durant, Spar, Emma, Aspen, and other ore bodies, is a knife-edge of bare rock which trends with the strike of the limestones that inclose the ore, and on

which, if anywhere, it should have been possible for the original locators so clearly to define their ore body as to avoid such disputes as these, which so seriously detract from its value. A perusal of the following pages will show, however, that it was utterly impossible for anyone to foretell from the surface indications what would be the form and position of these bodies in depth; and further, that while the inference that it was a deposit following a contact or bedding plane between two sedimentary beds was a proper and just one from surface indications, this contact is in reality a fault and not a single bedding plane; and that the ore has been deposited in this portion of the district, not along any single plane, but by waters following a complicated system of faults of constantly varying strike and dip, which it was utterly impossible to define in accordance with the terms of the United States mining law; and that the only possible way of defining the claim to such ore bodies is by vertical side lines, irrespective of the form or direction that the ore body may take in depth, a method to which the mine owners inevitably come in the long run, whether by compromise beforehand or after they have wasted their means in the enormous expenses inevitably attendant upon such lawsuits. In the other case quoted by Mr. Brunton, where there could be no outcrops of the ore bodies whatever, the hill being deeply covered with gravel and wash, the great skill exercised by the engineers employed by the mines and the acumen shown by the learned judge, who is famed for his knowledge and correct understanding of ore deposits, in explaining the two questions in dispute, did not result in a verdict that is strictly in accordance with the facts, for the present investigations have shown that the fault in question must have been formed prior to the deposition of the ore, but that movement on it has continued since that deposition, a condition of things that the law has not and could not have foreseen.

The conditions attendant upon the deposition of ore bodies in general are found to be more and more complicated as accurate studies of them progress, and they are not found to be identical in any two mining districts. It is therefore an inherent impossibility so to frame the definition of an ore deposit, if the owner is allowed to go outside of his surface boundaries vertically projected, that it will not give rise to litigation in a vast number of cases, or work great injustice to a large proportion of claim owners.

EXPLOITATION.

In the exploitation of its mines and the reduction of its ores Aspen has shown itself to be unusually enterprising, and has led the way in many improvements in either branch of mining. As early as 1882 smelting works were built at the northern edge of the town, which were run more or less continuously up to 1887. That they should be financially successful when obliged to depend on the ores from a single district was hardly to be expected, and when by the advent of the railroad they were brought into competition with centrally situated works at Denver and Pueblo, which drew their ore supplies from all parts of the mountains, they were naturally closed down. Extensive lixiviation works, designed by C. A. Stetefeldt, were erected in 1891 on the north bank of Castle Creek, and operated until the crash of 1893. They employed a modification of the Russell process. The financial success of these works is also said to have been doubtful.

There have been many sampling works in the district, the first of which was opened in 1883. At present there are two, the Aspen Sampler and the Taylor and Brunton works, and through them passes fully 90 per cent of the ores that are shipped from the district. These extremely useful institutions act as middlemen between the miners and the smelters. To the former they pay promptly the market value of their ore, carefully determined by reliable scientific methods, after deducting the necessary charges for sampling, freight, royalties, and smelting charges. To the latter they are enabled to furnish mixtures of ores containing the various metals in proportions desirable for smelting charges.

Situated as it is at the junction of three rapid and considerable mountain streams, which furnish a readily available water power, Aspen has unusually good opportunities for the location of power plants for generating electric currents, which may be used not only for lighting purposes, but also to transmit power to the many mines situated on the steep and difficultly accessible mountain slopes. It was among the first, if not the very first, of the mining districts to make use of electric hoists (July, 1888) and electric pumps in the mines. The entire plant of the new Free Silver shaft on Smuggler Mountain, designed for a depth of 1,000 feet and more, is run by electricity. There are at present two public companies for furnishing

electric light and power to the town and its mines, and no city in the State has better light for domestic purposes than Aspen.

For the transportation of ore down from and supplies up to the mines, situated high up on the hills, several aerial wire tramways of different systems are in operation. On both Aspen and Smuggler mountains long drainage tunnels have been run for drainage and extraction purposes. The longest of these, the Cowenhoven tunnel, which is owned by a separate and distinct company, is over 8,300 feet long, and is designed to tap all the mines beyond the Smuggler on Smuggler Mountain.

Of late years, since the largest and richest of the magnificent bodies of silver ore thus far discovered, and for which Aspen is justly famous, have been worked out, and since the mining profit has been so greatly reduced in all the mines of the district by the decline in the price of silver, the system of leasing the whole or parts of a mine to individuals or groups of miners has become common, as it is in other parts of Colorado. Under this system, while the mine owner may receive less profit from rich ground, the loss, if any, is distributed among a number of individuals and becomes proportionately smaller in each case. Greater economies are practiced where each miner has a personal interest in keeping the costs down to the very lowest figure, so that it is possible under this system to extract ore at a small profit, especially in old and abandoned workings, on which the company itself would probably lose money.

Various systems of leasing are employed in the district. Sometimes one or more individuals lease the whole of a mine and sublet it in portions to individual miners or groups of miners. The lessee frequently pays men to work for him at "grub wages," furnishing them only food and allowing a contingent interest in the profits.

In other cases the mine is divided into blocks of varying dimensions, which are leased to the highest bidder, the company retaining control of the mine and furnishing power, foremen, engineers, timbermen, skip tenders, etc., and requiring each lessee to work in a systematic manner and to keep his portion of the mine in proper condition.

The royalties paid vary greatly with varying conditions of lease and with the grade of ore that may be expected. In a certain mine the royalty was fixed for the year 1895 by the following sliding scale:

Royalty on ore.

Carrying Ag. (average to the ton)—	Per cent.
Up to 20 ounces	10
From 20 to 30 ounces	15
From 30 to 40 ounces	25
From 40 to 50 ounces	35
From 50 to 60 ounces	40
From 60 to 70 ounces	45
From 70 to 80 ounces	50
From 80 to 90 ounces	55
From 90 to 100 ounces	60
From 100 to 120 ounces	65
Over 120 ounces	70

The average returns under this schedule for twelve months are given at $6.43 profit per ton to the lessee and $5.24 to the company.

Another important mine, whose ores are exceptionally rich, charges a flat royalty of 70 per cent of the net returns.

PRODUCTION.

The ores of Aspen are essentially silver ores, and contain remarkably small amounts of other metals, with the exception of lead. Very considerable bodies of ore, notably the wonderfully rich bodies of polybasite and native silver found in the mines of Smuggler Mountain, are practically free even from lead.

Traces of gold have been found from time to time, but there is only one authentic case on record where the amount in a lot of ore was sufficient to be paid for by the smelter.

Copper occurs in appreciable amount in the Dubuque mine, in Queens Gulch, and in some of the deeper mines. It is not, however, noted in the settlings of the samplers, and hence must be in very small amount in the aggregate.

Zinc has been found in considerable amounts in the Aspen Contact mine, at Lenado, and in the Smuggler, Dubuque, and others, but does not play an important part in the average contents of the ores.

Lead is abundant in certain ore bodies, and may run as high as 70 per cent, but it is not possible to give the aggregate production of this metal in the district, for the reason that it is seldom accounted for in the mint statistics. In the Census reports for the year 1889 its value is given as $3\frac{1}{2}$ per cent of that of the total metallic product, the balance being silver.

It has not been found possible to obtain figures of production directly from the mines in all cases; hence this method of determining the aggregate silver product of the district had to be abandoned, and recourse was had to the only other available source, the records of the mint at Denver, which were gathered for it by different individuals in different years, and hence are liable to a large personal error. They may include some ores not strictly belonging to the Aspen district, the returns being made as from Pitkin County. In the following table, made up from these data, there having been no return given by the mint official for the year 1885, the amount for this year was determined by interpolation between the preceding and following years, and for the year 1889 the figures of the census were taken as having probably been estimated with more care and detail.

Finally, the figures for the year 1895 were obtained by calculating the tonnage given by samplers as the average contents in silver given by 306 assays of average ores, and adding 225,000 ounces shipped direct from mine to smelter.

Silver product of Aspen mining district, 1881 to 1895, inclusive.

Year.	Ounces of silver.	Coinage value.
1881	23,204	$30,000
1882	23,204	30,000
1883	42,540	55,000
1884	464,073	600,000
1885	460,000	594,734
1886	454,247	587,296
1887	639,336	826,597
1888	5,536,649	7,158,327
1889	5,677,308	7,340,184
1890	5,246,458	6,783,145
1891	6,963,289	9,002,830
1892	8,256,467	10,674,722
1893	4,443,310	5,744,749
1894	6,039,799	7,808,850
1895	4,963,690	6,417,555
Total	49,233,574	63,653,989

The notable changes in the above table are, first, the almost tenfold increase in production from the year 1887 to 1888, due to the advent of the railroads, and to the compromise of the apex side-line suit; second, the decrease of nearly one-half from the year 1892 to 1893, due to the sudden decline in the price of silver, and in part to the working out of some of the large bodies of very rich ore that had increased production greatly during the two or three previous years.

GEOLOGICAL INVESTIGATIONS.

The mines of Aspen were mostly discovered and opened by men whose most recent mining experience had been at Leadville, where the silver ores were found principally at or near the contact of limestone with overlying sheets of porphyry, and where the great faults, having been formed since the period of ore deposition, were barren of original deposits. In this new district, therefore, the miners naturally looked for similar conditions, and finding ore between the blue and brown limestone at their outcrop, assumed that it was a contact deposit between these two beds, and located claims accordingly.

When, in the summer of 1887, while engaged upon the survey of the southern Elk Mountains, the writer made a hasty reconnaissance of the Aspen mining district and its immediate vicinity, the contact theory was still held by a large part of the mining community, and those who did not partake in this belief had no very definite theory to offer in its place.

The writer's underground observations, which were made in the company of upholders of either belief, led him to conclude that the ore had been deposited along fault planes and from there outward into the body of surrounding limestone, but he saw that only thorough and careful work, based on most detailed maps, both of surface and of underground workings, could finally determine these questions on a scale of accuracy proportionate to the magnitude of the interests involved. He therefore urged upon the Director of the Survey the importance of having such a monographic study made of the district, but it was not until the summer of 1890 that it was found practicable to commence a survey for special topographical maps of the region. These maps, made under the direction of Mr. Morris Bien, were completed in the summer of 1891, and as soon as printed were distributed among those interested in Aspen mines. These persons, who had

opportunity in their daily work to subject the maps to the severest tests, have borne testimony to their high degree of accuracy. The geological examination of the district, which was planned for the summer of 1892, was necessarily postponed in consequence of the provisions in the appropriation act passed by Congress in July, 1892, which not only cut down the amount allotted to geological work, but specifically reduced the number of geologists employed, and resulted in the discharge from the Survey of the four geologists who were especially devoted to economic work, of whom the writer was one.

The present Director assumed control of the work of the Survey in July, 1894, but it was then too late to undertake so elaborate a piece of work as the Aspen survey, and it was therefore postponed until the season of 1895.

In consequence of a severe attack of pneumonia in the early part of that season, the writer was incapacitated for the arduous physical labor involved in the work planned, and was obliged to trust the practical execution of the work to Mr. J. E. Spurr, who had been his assistant during the previous season, and to content himself with acting in an advisory capacity and making two short visits to the district during its progress.

Mr. Spurr was occupied in the field work from June to December, 1895, and was assisted during this time by Mr. G. W. Tower. Too great credit can not be given to these two geologists for the zeal and energy which they have displayed in unraveling this most difficult problem in structural and economic geology in so short a time and in so thorough a manner. The magnitude of the work will be appreciated by an examination of the following pages and the atlas of maps and sections which accompanies the volume.

Having received orders to proceed to Alaska for an examination of the interior regions in the valley of the Yukon, Mr. Spurr has been obliged to complete his office studies of the material gathered, and the platting of the geological data on maps and sections, as well as the writing of the text, so as to leave for his new field of work by June 1. It has been thought best to publish the volume at once, even though, owing to the great pressure under which it has been written, there may have been less attention given to the form of presentation than if it had been more deliberately considered. For the facts, as well as for the theoretical conclusions presented, Mr. Spurr desires to assume the entire responsibility.

LITERATURE.

The following list comprises the principal scientific publications upon Aspen and its mines, as far as known to the writer:

1887. 1. Geology of the Aspen Mining Region, Pitkin County, Colo., by A. Lakes: Biennial report of the State School of Mines, Denver, 1887, pp. 45–84.

2. Preliminary Notes on Aspen, Colo., by S. F. Emmons: Proc. Colorado Scientific Society, Vol. II, Part 3, 1887, pp. 251–277.

1888. 3. Geology of the Aspen Ore Deposits, by L. D. Siver: Eng. and Min. Jour., Vol. XLV, Mar. 17, 1888, p. 195, and Mar. 24, 1888, p. 212.

4. Notes on the Geology and Some of the Mines of Aspen Mountain, Pitkin County, Colo., by Carl Henrich: Trans. Am. Inst. Min. Eng., Vol. XVII, May, 1888, pp. 156–161.

5. Aspen, Its Ores and Mode of Occurrence, by D. W. Brunton: Eng. and Min. Jour., Vol. XLVI, July 14, 1888, p. 22, and July 21, 1888, p. 42.

6. Geology of Colorado Ore Deposits, by A. Lakes; Denver, 1888, pp. 119–153.

1889. 7. Notes on the Geology of the Aspen Mining District, by W. E. Newberry: Trans. Am. Inst. Min. Eng., Vol. XVIII, June, 1889, pp. 273–278.

1890. 8. The Use of Electric Power Transmission at Aspen, Colo., by C. E. Doolittle: Trans. Am. Inst. Min. Eng., Vol. XIX, Oct., 1890, pp. 282–288.

1891. 9. Electricity in Mining as Applied by the Aspen Mining and Smelting Company, by M. B. Holt: Trans. Am. Inst. Min. Eng., Vol. XX, Oct., 1891, pp. 316–324.

1895. 10. An Experiment in Cooperative Mining, by D. W. Brunton: Eng. and Min. Jour., Aug. 3, 1895.

OUTLINE OF THIS MONOGRAPH.

The various divisions in the geology of the Aspen district are treated in this report in chronological order. Thus, Chapter I treats of the original structure of the sedimentary and igneous rocks and of the conditions under which they were laid down or intruded; Chapter II treats of the physical changes which have come about since their deposition, consisting mainly of folding and faulting; Chapter IV treats of the chemical changes which came about subsequent to or were attendant upon the physical changes, and were produced chiefly by metasomatic interchange, dolomization, silicification, ore deposition, and other phenomena; and Chapter V is a slight sketch of some of the surface changes which have occurred in comparatively recent times, since the ore deposition. Between the description of the physical and chemical changes is inserted a chapter describing in detail the mines and productive localities, this description being essential to the understanding of the various geological phenomena, especially that of ore deposition.

The fundamental rock in the Aspen district is a granite, with occasional gneissic structure. Above this come successively the sedimentary beds of the Cambrian, Silurian, Devonian, Carboniferous, Juratrias, and Cretaceous. The beds of the Cambrian, Silurian, and Devonian are comparatively thin, while the Carboniferous, which is divided into three distinct formations—the Leadville, the Weber, and the Maroon—attains a great thickness. The Juratrias and the Cretaceous are also very thick, the latter containing the various subdivisions of the Dakota, the Colorado, the Montana, and the Laramie. Separating these different beds at intervals are various unconformities and planes of erosion, which help one to read the history of the rock and to understand the conditions under which the beds were laid down.

Into these sedimentary rocks were intruded, probably in Cretaceous time, rocks of igneous origin. These are of two distinct types—one a diorite-porphyry and the other a quartz-porphyry. Both occur as sheets nearly parallel to the bedding of the sedimentaries, and as occasional cross-cutting dikes. The diorite-porphyry occurs chiefly as a single sheet, which widens toward the south and ultimately runs into the main diorite mass of the Elk Mountains. The quartz-porphyry, on the other hand, has probably ascended along narrow channels in the immediate vicinity of Aspen, and the structure of this rock shows it to belong to a type which characterizes the Mosquito Range, on the east side of the Sawatch, rather than the Elk Mountain district.

Subsequent to the deposition of the Laramie and the intrusion of these eruptive rocks, physical disturbance began. Among the first changes was the elevation of the Sawatch Range, so that the beds which lay round its flanks assumed a general dip away from the main uplift. At about the same time occurred some minor folding, which was apparently due to a lateral thrust exerted from the westward, and in the Aspen district was most pronounced in a narrow zone. Here an overthrown anticline was formed, which culminated in a great break, called the Castle

Creek fault. Probably beginning at the same period, but continuing afterwards, was the development of a domelike uplift, which affected both granite and sedimentary rocks in a restricted region east of the Castle Creek fault, now occupied by Aspen Mountain and Tourtelotte Park. This uplift was marked on the north side by a sharp bending-up of the strata, while on the west side the movement took place along the previously formed Castle Creek fault; on the other side the extent of the uplift can not be accurately judged, on account of its running into the granite. The bending-up of the beds was accompanied by faulting, which has gone on continuously from that time to the present day. At the beginning few faults were developed, but these appear to have had an important throw. As erosion progressively removed the overlying load of strata, the faults became more numerous and complicated, but the amount of throw in each case grew less. A number of distinct fault systems have been identified, differing chiefly in point of age. This difference in age is shown by the faulting of one system by a later system, and also by the fact that certain faults have developed before and certain others after the ore deposition. It is also shown that some faults have developed almost entirely in post-Glacial time, and that in many cases the fault movement is going on at the present day.

Along the channels afforded by faults hot-spring waters rose and brought about certain chemical changes. One of the most interesting of these is dolomization, and the combined evidence at Aspen and at Glenwood Springs, where the change is now being brought about by hot ascending waters, shows that the process is essentially a chemical interchange effected between the calcium carbonate in the limestone and carbonate of magnesia brought in by these circulating waters. Thus zones in the limestone following watercourses which are parallel to the bedding or which cut across it are locally altered to dolomite. There is, however, evidence of an earlier period of dolomization, which preceded the faulting and probably came about very early in the history of the rocks. Thus the Silurian sediments and those of the lower part of the Leadville formation were early converted into dolomite, probably by the action of magnesium salts contained in the waters of a shallow and evaporating sea.

Associated with the formation of the dolomite along fault fractures and watercourses is the deposition of silica and of iron, and both these processes must be referred to the same cause as the dolomization.

The ores of the district consist chiefly of lead and zinc sulphides, carrying silver, with a gangue of barite, quartz, and dolomite. On oxidation the sulphides change to sulphates, carbonates, and oxides. The deposition of the metallic minerals has taken place almost exclusively along the faults, but it is only in certain places that the fault zones become sufficiently mineralized to form valuable ore, for it is chiefly at the intersection of two or more faults that rich shoots are formed. The intimate association of the metallic sulphides with dolomite, quartz, and other gangue materials suggests a common origin for all—that they were deposited by ascending hot waters. Since the ore has been found chiefly at the intersection of faults, the theory is advanced that solutions ascending along one of these channels were precipitated by solutions which circulated along the other.

Among the more recent chemical changes in the rocks, mainly subsequent to the ore deposition and its attendant phenomena, is the formation of sulphates. Thus a considerable quantity of gypsum has been locally precipitated, and soluble sulphates occur as incrustation on rocks which have been exposed to oxidizing influences. By a process of reduction there has also been locally formed a large amount of native silver.

The ore deposits have been laid open to the hand of man chiefly by erosion, which has stripped off the overlying rocks and has carved deep valleys through the metalliferous deposits. It is estimated that since the beginning of disturbance 15,000 feet of sediments have been removed from that part of the Aspen district which lies east of the Castle Creek fault. The most recent of the erosive processes was glaciation. There is evidence that a general ice sheet at one time covered the whole of the Aspen district, moving over hill and valley westward from the Sawatch This has left its trace in the rounded and fluted forms into which the hilltops are carved, and in deposits of morainal material, generally finely ground. Subsequently this ice sheet shrank to smaller dimensions, so that there resulted local glaciers which followed the course of preexisting valleys and carved them into their present forms. These glaciers have left lateral and terminal moraines. At about this period, also, there existed in the Aspen Valley temporary lakes, probably resulting from damming-up of the glacial waters.

GENERAL VIEW OF ASPEN AND VICINITY.

GEOLOGY OF THE ASPEN MINING DISTRICT OF COLORADO.

By J. E. Spurr.

CHAPTER I.

ROCK FORMATIONS.

GRANITE.

Oldest of all the rocks in the Aspen region is granite. This rock, often changing into gneisses and schists, forms a permanent floor on which all the sedimentary rocks rest, and through which, so far as is known, all the other igneous rocks have forced themselves to reach the position in which they are now found.

Description.—This granite presents a considerably diversified appearance even over a limited area, but these variations are all in reality slight structural modifications of one type, for chemical and microscopic work shows that the rock possesses a remarkable uniformity. The variations from an originally uniform rock seem to have been brought about by slight differences in local conditions, and often by changes which have occurred since the original consolidation of the rock; and in many cases the nature of these changes can be discerned. Within the limited area shown on the special maps of the Aspen district (which was as far as careful study was carried, although frequent reconnaissances into the surrounding territory were made for confirmation of the results here obtained), the granite is mostly of a massive character. The most common variety is moderately coarse, of a general light-green color when fresh, and reddish-brown when weathered. It has a coarse granular texture, and the constituent minerals

of granite can be easily recognized megascopically—bluish quartz, yellowish or pink feldspar, and mica. The mica is brown when fresh, but most of the granite has been slightly altered, and this alteration changes the color of the mica to a dark green, which gives the characteristic color to the rock where it has not been actually exposed to the atmosphere. Where such is the case the active oxidation changes the condition of the iron in the mica and its alteration products, so that the prevailing color of the rock changes from green to the red of iron oxide. The beginning of this alteration is first seen megascopically in the feldspars, for, as is shown by the microscope, the first solutions of iron derived from the mica and other ferruginous minerals penetrate into the colorless feldspars along their cleavages and there deposit their iron as oxide. It is in this manner that the characteristic pink color of the feldspars is produced

Variations of the granite occur in places not far from Aspen, in the form of considerable areas of gneisses and schists, but in the Aspen district such rocks are not found to any extent. In some places, however, there is a slight gneissic structure developed, and these beginnings of parallel arrangement are interesting as having a bearing on the history of the more completely altered rock. A common type of such gneissic rock is coarser in grain than the ordinary variety, is of a dark-green color, and is made conspicuous by its brick-red feldspars, which have developed a porphyritic habit. There are irregular but in a general way parallel parting planes running through this rock, which are often polished and striated; these show that the parting is due to deformation of the granite at some time later than its consolidation, and is not an original characteristic. This conclusion is also reached by microscopic study. Another type of gneissic granite is considerably finer grained than the ordinary rock, so that it has almost a schistose appearance. This rock seems peculiarly liable to oxidation, and is therefore often of a reddish color. It contains many small flakes of dark mica, which have a parallel arrangement, and in many places these mica plates, while still preserving their perfect parallelism, are concentrated into spherical or lenticular bunches, which do not have crystalline boundaries. The bunches are similar to the "eyes" of the so-called augen-gneiss, so that the rock is transitional between this rock and granite. Whether the large porphyritic crystals of the one variety of gneissic granite and the lenticular aggregations of mica in the other have

a common origin, and whether they have any genetic connection with the sheared structure which is found in both cases, is not certain; but the absence of such porphyritic development in the massive granite is significant.

Microscopic structure.—The essential constituent minerals of the granite, as seen under the microscope, are quartz, feldspar (mostly microcline), biotite, and muscovite, and it thus belongs to the rocks classed by Rosenbusch simply as granite, or "granite proper." No hornblende or augite was found. As accessory constituents there are magnetite, apatite, and zircon. Most of the minerals are usually comparatively fresh; but there is a slight kaolinization of the feldspars and an alteration of the biotite, resulting in the abstraction of iron, which is first concentrated along the cleavages of the mineral and then carried out into the rest of the rock. The feldspar usually shows microcline structure, the partial development of which can sometimes be seen in a crystal which otherwise has the characteristics of orthoclase, indicating that the structure has been induced by pressure, as suggested by Rosenbusch.

The gneissic varieties of the granite have under the microscope a structure in general like that of the massive rock. In the fine-grained variety mentioned above there are some slight but interesting metamorphic changes. The mica in this rock is both biotite and muscovite, occurring intergrown, and comparatively fresh. The usual accessory minerals, apatite and zircon, are present chiefly as inclusions in the quartz, feldspar, and mica, and tourmaline is found in small quantities. The occurrence of this mineral is interesting, since it was not found in the massive granite, and is therefore probably a product of metamorphism. Specular iron, red hematite, and earthy limonite, all evidently secondary, are present, and give the red color to the rock, although the structure is granitic, yet the effect of the strain which has operated to produce the gneissic arrangement, and probably the lenticular aggregates of mica, is plainly visible. The cleavage of the feldspar is strongly developed, sometimes resultıng in slight faulting. Within the quartz grains the effect has been to produce fine, straight fractures, which are intermittent instead of continuous, and the different sets characteristically form isolated crosses. These fractures are most numerous in the center of the grain, whence they diminish in frequency toward the edges. (See fig. 10, p. 229.)

Origin.—It was formerly assumed that a part at least of the Archean granite of the Rocky Mountain region was metamorphic in nature, having been produced by the profound alteration and crystallization of sedimentary beds. In the Aspen region, however, there is no evidence of any sedimentary origin for the granite; its structure shows only that it has consolidated from fusion, without hinting whether or not the materials of which it is composed were ever exposed to atmospheric influences before the present stage in its history.

CAMBRIAN SEDIMENTS.

Description.—In the Aspen district, as elsewhere in Colorado, there rests directly upon the granite a thin bed of conglomerate, which soon passes upward into fine white quartzites. The very lowest layer is an arkose or granitic grit, made up of the materials of the underlying granite, only slightly rearranged before deposition, so that the exact line of demarcation between granite and sedimentary rock is often difficult to distinguish within a foot or two. This difficulty is increased by the fact that the granite is in many places disintegrated for some little distance below the contact. Directly above the contact, however, the material begins to be more systematically arranged, the fragments of granite disappear, and quartz assumes the most prominent position among the minerals. This mineral occurs in bluish translucent grains which average about the size of large shot; these are generally inclosed in a fine paste, of kaolinic nature, derived from the decomposition of the feldspar in the granite. The size of these grains diminishes as the distance from the granite increases, so that the rock becomes fine-grained, compact, and of a bluish color, being made up almost exclusively of small rounded grains of granitic quartz, which have been cemented together by secondary quartz since their deposition.

Microscopic structure.—Under the microscope the lowest layers of these beds are seen to be made up mostly of granitic quartz and feldspar, the quartz being strained and fractured, as is typical in the granites, and the feldspar, which is often quite fresh, being mostly microcline. Alteration of the feldspars has produced aggregations of kaolin and muscovite. Among the smaller rounded grains which fill the interstices between the larger pebbles quartz is most common, with kaolin and finely divided and irregularly packed calcite which has the aspect of lime mud. There is generally some iron in the section, which from its position is evidently secondary, and is

derived from the alteration of the ferruginous minerals of the granite; it is either in the form of pyrite, in small crystals, or of specular iron or limonite, the former either in hexagonal crystals or in shells around an oxidizing crystal of pyrite, and the latter in irregular bunches disseminated throughout the rock. The successive alteration of pyrite to specular iron, or red hematite, and the hematite to yellow earthy limonite, in concentric shells, is often well shown; there is also occasionally some iron carbonate developed as an alteration product. Besides this secondary iron there are occasional grains of magnetite and red hematite, which from their shape and position are evidently of detrital origin.

Farther up in the beds the structure is essentially the same. With the diminution in size of the quartz grains the feldspar becomes more rare and the feldspathic cement almost disappears. The cementing material is then made up of secondary quartz, which has grown on to the original grains. Tourmaline is also found among the detrital grains.

Dolomitic quartzite.—The upper third of this formation is not so compact and pure as the rest. In fresh specimens this rock appears pure and homogeneous, but where it has been exposed to oxidation, as in all outcrops, it assumes a different appearance. The alteration is usually most marked along certain zones which are parallel to the bedding; along these the rock crumbles and is eroded, while the harder unaltered parts stand out, producing a striking banding of brown and white. This tendency to oxidation increases toward the top of the series, so that in places the whole rock is altered.

The microscope reveals very clearly the reason for this change. In the white, unaltered rock, there are found in the interstices between the rounded quartz grains, besides the secondary quartz, many scattered crystals of a carbonate, which, from its occurrence in isolated crystals of simple rhombic form and of grayish color, as well as by the analysis of the rock, is shown to be dolomite. This dolomite seems to have crystallized at the same time as the secondary quartz. That it was probably derived, however, from the alteration of original calcareous sediments is shown by the circumstance that it is much more common in certain zones than in others, and that these zones correspond to the bedding. In other sections it is shown that the dissolution of these dolomite crystals is the cause of the rapid alteration of the rock. By their removal, cavities are produced

which are afterwards enlarged by solution of the quartz. The secondary quartz cement appears to be more easily dissolved than the detrital grains, so these grains become partly isolated, and the rock in some degree returns to its original condition of sandstone. Some of the smaller grains which are thus isolated are carried out of the rock mechanically, so that the cavities continually widen, until the rock becomes so cellular as to be hardly able to hold together, and finally crumbles into soil. The iron which gives the brown color to the weathered rock does not seem to be derived from the rock itself, but to be secondary. It is a yellow hydrated oxide, very small in amount, which is deposited in thin coatings on the walls of the cavities and in interstices. In places, however, especially toward the top of the beds, there are many irregular nodules and seams of hard hematite, which microscopic study shows to have been formed by actual replacement of the quartzite, the quartz having been gradually dissolved to make way for the iron. In this process the quartz cement is first dissolved, so that the ore contains isolated bits of quartz, which are sometimes fragments consisting of several grains, but usually single grains which have been stripped of their cement, and the ragged and corroded outlines of the grains themselves show that they are also undergoing replacement, although more slowly. The source of the numerous iron nodules in this horizon is probably the oxidation of glauconite in the beds immediately above.

Glauconitic grit.—Above the altered dolomitic sandstones comes a thin bed which presents in the field certain striking characteristics that readily separate it from the beds above and below. The bed is not more than 15 or 20 feet thick, compact, and of a peculiar reddish color, mottled with yellow on weathered surfaces. It is of fine grain, but contains many greenish crystals of calcite, which, though small, have a porphyritic appearance; there are also greenish fragments of detrital feldspar, so that the rock resembles in appearance an altered eruptive rather than a sedimentary. It has a granular texture, an irregular fracture, and is distinctly heavy.

Under the microscope the rock is seen to be made up, in large measure, of detrital grains of quartz, feldspar, and mica. The feldspar is sometimes quite fresh, but is oftener altered to a muscovitic aggregate; the mica is colorless. Apatite and zircon are found in perfect crystals inclosed

by the other minerals. The detrital grains are surrounded by a cement of coarsely crystalline carbonate, probably dolomite. Associated with the granitic minerals referred to are many rounded bodies which are quite peculiar. These are made up in varying proportions of specular iron, dark-brown in color and with metallic luster; red, translucent hematite; limonite, yellow and earthy; cloudy siderite; quartz; matted actinolite; and calcite. These are generally confusedly and finely intergrown, although often they are in alternating zones. The cores of many of the grains are of siderite, which is oxidized around the edges to red hematite and limonite. Others have a core of specular iron, which appears to be very slightly magnetic; this alters, in part, to red micaceous hematite, but oftener to siderite. The structure of the grains suggests the alteration of glauconite, such as has been described by the writer from the Mesabi range in Minnesota.[1] The iron is almost entirely confined to these spherical areas, and there appears to be no channel by which it could have filtered into the rock, nor any definite arrangement suggesting such an origin. The nature of the rock in which they occur, being that of a sediment transitional between the zone of active deposition of eroded land materials and of the limestone deposition of the quieter seas, accords with this idea, for it is in such a transition zone that the peculiar conditions necessary for the formation of glauconite are obtained.

Beds prominently glauconitic occur at this horizon throughout a large part of the Rocky Mountains. In Colorado they were noted in many places by Peale[2] at this horizon, among others on the Eagle River; and Mr. Eldridge[3] has noted them in the Crested Butte district.

Sandy dolomite.—Above this glauconitic grit there is a gradual and perfect transition to the massive siliceous dolomite of the Silurian. The transition beds are made up at the bottom of detrital material and of dolomite, with the former generally in excess; a little farther up the relative amounts of the two are about equal; and toward the top the detrital material is displaced by the dolomite. The rocks have the appearance of more or less ferruginous sandstones and shaly, siliceous limestones. In color they vary greatly, being sometimes gray like the dolomite above, often reddish, yellow, or brown. Under the microscope the detrital grains, besides quartz,

[1] Bull. Geol. Nat. Hist. Survey Minnesota, No. X, 1894.

[2] A. C. Peale, Annual Report of the Hayden Survey for 1874, p. 112.

[3] G. H. Eldridge, Geologic Atlas U. S., folio 9, Anthracite-Crested Butte, Colorado, p. 6.

are found to be of feldspar, mica, and occasional tourmaline; in shape they are generally subangular, sometimes angular, often rounded. The dolomite is like that of the pure dolomite beds above—uniform in grain and crystallized in gray interlocking rhombohedra, and often a small detrital grain of quartz or feldspar is entirely inclosed in a single crystal of dolomite.

Thickness of beds.—The thickness of the quartzite and sandy dolomite series varies greatly in the Aspen district, being greatest in the southern part, where it is about 350 or 400 feet, and gradually decreasing toward the north; so that in the northern part it averages 200 feet or less.

Age.—No fossils were found in these beds, but they are lithologically identical and are continuous with the well-known series which extends over a large part of Colorado, lying around the borders of the granite area of the Sawatch. From fossils found in various places at this horizon these beds have been unanimously referred to the Upper Cambrian. It is not, however, clearly established at just what place in the beds the top of the Cambrian and the bottom of the Silurian should be put. Mr. Emmons[1] has arbitrarily drawn this line at the top of the shaly beds and the commencement of the more massive dolomite, and the same line is adopted in this report.

Conditions of deposition.—According to Mr. C. D. Walcott,[2] Colorado, at the beginning of Cambrian time, formed part of a large island, which had a north-south extension of about 1,000 miles and a width of about 300 miles. The island consisted of the Archean crystalline rocks and whatever ancient sediments had accumulated previous to Cambrian time. At about Middle Cambrian or the middle of Upper Cambrian time there was a subsidence of the land, so that a large part of it was brought beneath the waters of the ocean, and on this submerged area were deposited the sediments of the Upper Cambrian which have just been described. The first material was only slightly rearranged from the granite, which apparently was already disintegrated from atmospheric corrosion, while that laid down later was evidently deposited in water which grew continually deeper, as is shown by the careful sorting, by the small size to which the quartz grains became reduced, and by the mingling of dolomite with the detrital materials in the upper beds. When the dolomitic materials became nearly equal in amount to the detrital grains, conditions were favorable to the formation of glauco-

[1] S. F. Emmons, Mon. U. S. Geol. Survey, Vol. XII, 1886, p. 59.

[2] Bull. U. S. Geol. Survey No. 81, 1891, p. 368.

nite; and it is interesting to note that those conditions were the same as those under which the mineral is formed at the present day. The continuation of the subsidence of the ocean floor is indicated by the gradual disappearance of the detrital material and the formation of the purer siliceous dolomite, which belongs to the Silurian age. There is, however, no discernible break or cessation of deposition between the two periods, but all indications are that the sediments were deposited continuously.

SILURIAN BEDS.

Description.—The pure dolomites above the sandy beds are generally light gray-blue in color, sometimes stained reddish; they weather yellow-brown, from the oxidation of the small amount of iron which they contain, and are hard and compact, with a fine frosty luster which is characteristic of these, as well as of the Carboniferous dolomites. This luster results from the structure of the rock, which is made up of small interlocking crystals of dolomite, nearly uniform in size. There are usually blotches, nodules, bands, and seams of chert, which is generally light gray in color. The nodules are often very irregular in shape; when they become elongated into seams or bands they generally conform to the bedding, although sometimes they cut across it, at various angles. The only noticeable difference between the bottom and the top of the formation is that at the top the dolomite is locally finer grained than at the bottom, the crystals often becoming so small that the frosty luster coming from their facets is very faint.

Microscopic structure.—In mineral composition this rock is like most dolomites, being made up of small, interlocking, nearly uniform crystals. Another mineral which is never absent from any thin section is quartz, generally pretty evenly disseminated in isolated grains of small but varying size. On casual examination they appear like detrital grains, but when carefully observed it is found that their outlines, instead of being rounded, or even regularly angular, are often irregular and sinuous, presenting reentrant angles and sudden bays, such as would not occur in a grain which had suffered any friction whatever. The quartz, moreover, is clear and free from any break or crack, such as characterizes detrital quartz, especially in that derived from granitic rocks. The grains are usually smaller than the dolomite crystals, and the crystallization of the

carbonate is not in any way affected by their presence, so that often a quartz grain is entirely inclosed in a single crystal of dolomite. In certain areas, however, these quartz grains become more numerous and cluster together, and irregular portions may be made up mainly of quartz, while closely adjoining portions are chiefly of dolomite. Where the silica is thus concentrated into an area of considerable size a chert nodule is the result. The silica then becomes cryptocrystalline and sometimes chalcedonic, and it incloses some carbonate in the form of rhombohedra, sometimes scattered sparingly through the chert, sometimes becoming very numerous. Besides the small rhombohedra, there are larger irregular areas which have the typical structure of dolomite, consisting of numerous small interlocking crystals; these are evidently residual, while the isolated rhombohedra, which have a marked zonal structure attesting gradual growth by successive additions, are evidently concentrations of similar smaller residual areas.

When the rock is strained so that oxidizing agents have obtained entrance along cracks, there is often formed uniformly throughout the rock a small amount of iron oxide, which occurs along the cracks themselves, between the crystals of dolomite, and along the cleavage, especially where this is strongly developed by the strain. The oxide seems from its arrangement to be derived from material already in the rock, rather than that brought in along the crevices; and analyses of the fresh rock usually disclose a small but constant percentage of iron. This iron is probably in the form of carbonate, and is crystallized with the dolomite.

Thickness of beds.—This dolomite varies in thickness in the same way as do the Cambrian beds below it, thickening gradually toward the south and thinning toward the north of the area mapped; the maximum thickness at the southern margin of the Tourtelotte Park special area being about 400 feet, while at Lenado the average is probably 250 feet.

Age.—The age of these beds is fixed as Silurian by fossils which have been found in the same formation in various parts of Colorado, but no further subdivision can well be made. This horizon was assigned by Peale[1] to the Calciferous epoch, at the base of the Silurian series, while Mr. Emmons[2] reported not only fossils of the Calciferous epoch but also some which resembled forms of the Niagara and the Trenton. What

[1] A. C. Peale, Ann. Rept. Hayden Survey for 1874, p. 112.
[2] Mon. U. S. Geol. Survey, Vol. XII, 1886, p. 61.

evidence there is, therefore, goes to show that the dolomite is of Lower Silurian age.

Origin of the dolomite.—It is practically agreed upon by geologists that dolomite as a rock is nearly always formed by the alteration of calcareous sediments subsequent to their deposition.[1] The structure of the Silurian dolomite at Aspen, as seen under the microscope, is not that of a sedimentary deposit, since it is made up of interlocking crystals and of quartz which has evidently formed in place without any important amount of detrital material. This structure is sufficient evidence that it has crystallized through the influence of solutions; and the question presents itself as to whether this rock was deposited as such from oceanic waters, or whether it is the result of the alteration and recrystallization of an original simple sedimentary deposit. The theory of a chemical precipitation of carbonate of magnesia requires the assumption of a shallow evaporating salt lake or inland sea, in which carbonates of lime and magnesia derived from solution of rocks were concentrated and finally thrown down.

Bischof,[2] however, has shown that owing to the difference in solubility between the carbonates of lime and of magnesia the lime carbonate will be nearly all deposited from a saturated solution containing both these salts before the precipitation of the magnesia carbonate begins; consequently there would result from a deposit formed in this way a lower layer of nearly pure carbonate of lime and an upper layer of nearly pure carbonate of magnesia. There might be some mingling of the carbonates in the zone between the two layers, but no important amount of dolomite could be formed in this way. There are no cases known where such a process of formation of dolomite is now going on.

On the other hand, there have been many cases described where dolomite has been produced along narrow zones which often cut across the bedding of the limestone. Such alteration has been described by Harkness[3] in the south of Ireland, where narrow bands of dolomite have been produced along joints, and the conclusion is inevitable that here the dolomite has been produced by the metamorphosing action of waters which have penetrated the limestone along these joints at some period subsequent to the

[1] Dana, Manual of Geology, fourth edition, p. 133.
[2] Chemical and Physical Geology, Vol. III, p. 170.
[3] Robert Harkness, Quart. Jour. Geol. Soc. London, Vol. XV, p. 100.

deposition and the jointing. The same phenomenon is observed in the Carboniferous blue limestone at Aspen, where the limestone is altered along joints and fault-planes to brown crumbling dolomite, locally known, from its finely jointed structure, as "short lime." The microscopic structure of the dolomite, which evidently arises from the alteration of limestone, is essentially like that of the dolomite of the more massive and extensive beds, as Sorby[1] has noted in the dolomites of Europe, and as the writer has found by a thorough study of the Aspen rocks. The structure of the Silurian dolomite, therefore, is one which may arise from the alteration of a calcareous sediment. The persistence and uniformity of this dolomite, which retains practically the same composition for hundreds of miles, show, however, that the cause of its alteration could not have been local, as in the case of the narrow zones which follow joints and dikes, and which were the result of transient circulating waters. The alteration of the Silurian dolomite from an assumed original calcareous sediment demands the action of waters throughout its whole extent for a considerable period of time. Such a condition would be afforded by the presence of a great lake or inland sea, in which the usual amount of magnesia in sea water would be concentrated by the evaporation of the water. This is actually the condition which is considered by most geologists to have brought about the formation of nearly all, if not all, of the persistent and widespread dolomites. Dana[2] mentions an interesting case of actually observed dolomization at the coral island of Metia, north of Tahiti. The rock of this island is a compact white coral limestone, which has nearly the composition of true dolomite, showing on analysis 61.39 per cent of calcium carbonate and 38.07 of magnesium carbonate. The general character of this rock leads to the inference that it was deposited from the waters of the shallow lagoon of the coral island in the form of fine coral mud, that the waters of the lagoon became concentrated by evaporation so as to contain a much greater proportional amount of the magnesium salts than is normal in sea-water, and that these solutions brought about the dolomization of the coral mud. The magnesium salts of the ocean consist chiefly of chloride, and this is quite capable of accomplishing the change in question.

It is probable, therefore, that the Silurian dolomite of the Aspen district was originally deposited slowly in quiet seas, and was built up

[1] British Assoc. Report, 1856, p. 77. [2] Corals and Coral Islands, p. 393.

from calcareous sediments; that these beds were subsequently altered to dolomite by the magnesium salts of a great evaporating shallow inland sea; and that this alteration was accompanied by the production of the crystalline structure now characteristic of the rock.

PARTING QUARTZITE SERIES.

Above the Silurian dolomite comes a series of thin beds which from their persistence and peculiar characteristics are extremely valuable in determining stratigraphical questions, for they form a marked and unmistakable dividing zone between the dolomites of the Silurian and the upper dolomites, which are almost identical in structure and appearance with those of the Silurian, but which are of Carboniferous age.

Description.—On the top of East Aspen Mountain, overlooking the town of Aspen, a section of the Parting Quartzite, which was here exposed on the face of a cliff for its full thickness, was carefully observed and measured. The section is as follows from below upward:

Section of Parting Quartzite exposed on East Aspen Mountain.

1. Hard, dark-blue Silurian dolomite, passing upward into very thin bedded or shaly light-gray dolomite .... 6 inches.
2. Greenish-gray sandstone, made up of quartz grains of varying size in a dolomitic matrix .... 2 feet.
3. Hard, dark-blue dolomite, like that first mentioned .... 2 feet.
4. Hard, white quartzite, weathering reddish .... 1 foot.
5. Dolomitic sandstone, like No. 2 .... 1 foot.
6. Thin-bedded, gray dolomite shales, like No. 1 .... 2 feet.

Above this, in ascending order, one passing somewhat gradually into the other, come—

7. Fine-grained limestone or dolomite, very much like No. 2 and No. 5, with many quartz grains, and occasional thin seams of shale .... 3 feet.
8. Thin-bedded lime or dolomite shales, light green when fresh, weathering yellowish-brown, and, when looked at from a little distance, having a general maroon color. This color is due to a rich dark-brown staining, which is nearly solid at the bottom of the bed; near the top, however, it is in bunches, and is made up of curiously curving, thick, concentric rings .... 4 feet.
9. Fine-grained, light-brown dolomite, with smooth, conchoidal fracture; contains many quartz grains, and is a transitional type between No. 8 and No. 10 .... About 1½ feet.
10. Hard and compact dolomite, light gray in color; from its uniform aphanitic structure and regular conchoidal fracture, as well as from its delicate coloring, this rock is one of the most characteristic of the series. It has been called in the field "lithographic stone," from its having a very close resemblance to the peculiar limestone which is used commercially for lithographic purposes .... 8 feet.
11. Light-colored, fine-grained dolomites, resembling those of No. 10, but becoming thin-bedded and shaly .... 12 feet.

12. Dolomite, essentially like No. 10 .... 3 feet.
13. Like No. 12 in structure, but blue or brown in color, and containing occasional sand grains .... 12 feet.
14. Hard, white quartzite, weathering yellow-brown .... 2 to 4 feet.
15. Sandy, brown, crystalline dolomite, fine grained, with frosty luster, passing upward into the dark-blue dolomite of the Carboniferous .... 10 feet.

On the south-facing cliff of Castle Butte, which overlooks Queens Gulch, the beds of the Parting Quartzite series are also exposed in their full thickness. Here the examination made was not so detailed, but in a general way the series consists of a basal impure quartzite, a shaly bed stained a deep-maroon color, a heavy, light-green lithographic dolomite, and at the top of the series a heavy quartzite. The thickness of the section in both places is nearly the same, namely, about 60 feet.

The quartzites at the top and the bottom of the series, the gray, light-green, or light-brown massive lithographic dolomite, and the dark-brown shaly beds are the characteristic features of this horizon in the Aspen district, and are nearly always present, although the minor stratigraphy varies considerably, so that the detailed section of the beds on East Aspen Mountain is probably only local and might not hold good for any other part of the district. On account of the prevailing colors of the chief members of this series, they are known in Aspen as the gray, the green, the maroon, and the white beds, the gray and the white being chiefly the quartzites, the green the lithographic dolomites, and the maroon the high-colored dolomitic shales. The series may be summed up as broadly characterized by an impure feldspathic quartzite at the base and a heavier and purer quartzite at the top, with an intermediate series of massive lithographic dolomites and shaly dolomites. The shaly dolomites are richly colored, chiefly brown and green; the colors are sometimes solid, oftener banded, mottled, or arranged in rings.

Microscopic structure of the basal quartzite.—In appearance the basal quartzite is quite ordinary, being light gray, light green, or pure white in color. In texture it is sometimes uniform, but oftener incloses grains of different sizes, varying from the minutest dimensions up to an eighth of an inch in diameter. It is also remarkable for carrying bands or blotches of the gray lithographic dolomite into which it passes above. Under the microscope there are found, besides the quartz, detrital grains of feldspar, chiefly microline, and subangular or rounded fragments which are made up of interlocking crystals of carbonate and are evidently detrital fragments of

limestone or dolomite. There is also occasional tourmaline. The detrital grains are inclosed in a cement which is made up partly of finely granulated carbonate, apparently limestone or dolomite detritus, but mainly of a white opaque substance, which is probably kaolin. In places this matrix predominates in quantity over the included grains.

In the typical case which has just been described there is no cementation of the original grains by secondary silica, and therefore the rock is not a true quartzite, but a feldspathic and dolomitic sandstone. This sandstone passes on the one hand into the sandy lithographic dolomite and on the other into a more siliceous variety which has a true quartzitic structure. This latter rock has a cement of secondary silica; further evidence of alteration from an original sandstone is the carbonate, which is concentrated into irregular crystalline patches.

The third variety of the basal quartzite member—the sandy lithographic dolomite—is developed very gradually from the dolomitic sandstone by an increase in amount of the dolomitic material and a decrease in the size and number of the detrital quartz grains. In sections of this rock the angular, subangular, or rounded grains of quartz are scattered in a mass of very finely crystalline dolomite, which is homogeneous and probably represents a lime mud. There are also many areas of cryptocrystalline dolomite; these have sometimes a rounded, sometimes an angular or irregular outline. This cryptocrystalline dolomite is the gray "lithographic limestone" of the field; in the hand specimen it appears as small irregular patches, which sometimes unite to form nodules or bands.

The lithographic dolomite member.—Where found in fresh condition, as in mine workings where oxidizing agents have not been very active, the prevailing color of the lithographic dolomite is a light, delicate gray, with a tinge of green. On oxidation, however, it turns chocolate-brown, and outcrops invariably have a brownish tinge. Owing to the fineness and uniformity of grain and the compactness of structure, weathering causes it to shell off on exposed surfaces, so that it presents in the outcrop rounded knobs of comparatively fresh rock, smooth to the touch. Microscopically the structure is that which has just been indicated. The main mass of the rock is of carbonate, cryptocrystalline or very finely phenocrystalline; through this are often disseminated small detrital quartz grains. In specimens which have undergone some slight alteration, apparently from under-

ground waters, there is a secondary growth upon these grains, so that they often become perfect crystals. Crystals of pyrite are also often found. Such specimens are usually traversed by a system of fractures, indicating the nature of the altering agents, and these fractures are filled with fresh crystalline calcite. The coloring of the rock on oxidation is due to the formation of very small but uniformly disseminated amounts of iron oxide. In those rocks which contain pyrite some of this oxide is seen to come from the alteration of the sulphide; but as the change takes place also in rocks which have no trace of pyrite, it is probable that there exists a small amount of iron in the fresh rock, in the form of carbonate. Analyses of the rock show it to be strongly magnesian, although the amount of magnesium is not always quite equal to that in normal dolomite.

The maroon member.—Structurally this is simply a variety of the sandy lithographic dolomite, which is thin bedded and sometimes shaly, and so has been especially easy of access to altering agents, which have given it its brilliant coloring. The more compact dolomite in the vicinity of these shaly beds often partakes of their peculiarities of tint, showing that the color does not arise from any original difference.

Three different processes of coloring have been noted—one of reduction, one of oxidation, and one of leaching by surface waters. The process of oxidation gives the dark-red or maroon color; that of reduction a dark-gray, dark-green, or nearly black color; that of leaching a light-yellow to nearly white color. The coloring matter is probably chiefly iron, although the brilliancy suggests the presence of some of the other metals. The various stages of the oxidizing process are well seen in the specimens taken from mines. The fresh rock is a vivid light green for the most part; and while this may not have been the original color, it is the earliest stage which has been observed. This becomes red in places, there being a variety of transitional tints, which are often symmetrically concentrated into concentric rings; in others there is a very sharp line between the red and the green portions of the rock, and as these portions are irregular in shape and intimately mingled, there results a pronounced mottling. The oxidation is accompanied by a shrinking of volume, so that while the green rock may be hard and compact, the red is closely jointed and brittle. When the rock is mostly altered to the red it still contains small rounded or lenticular residual areas of the green, often no larger than peas or shot. (See fig. 1.)

The alteration of the maroon color to banded light and dark green, by a process of evident reduction, was observed in a specimen kindly given by Mr. D. W. Brunton, of Aspen. This specimen was from the Free Silver shaft, about 700 feet below the surface. The color of the rock is the typical dark red of the oxidized Parting Quartzite series. In the vicinity of a set of fine, almost microscopic fractures, which, however, have been brought into prominence by the concentration of the reduced iron along them, the rock is altered to a light-green color, with bands of darker

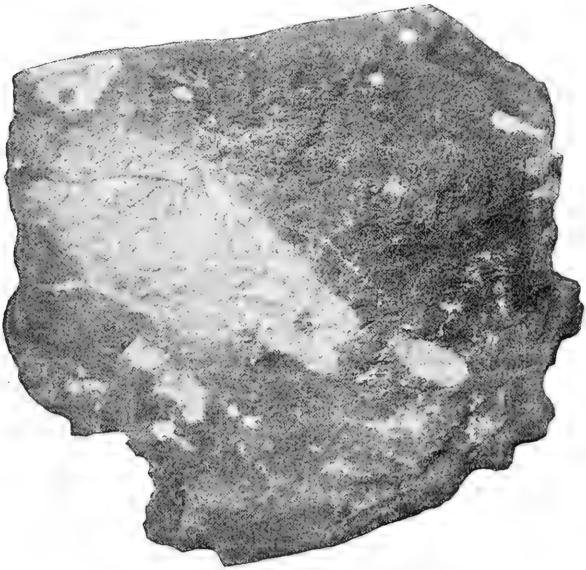

FIG. 1.—Oxidized fine-grained dolomite, with residual areas.

green following each of the individual fractures. The width of the largest band thus altered is about an inch and a half, while smaller bands of varying width ramify from the main one (see fig. 2). Within these altered zones there are discernible numerous small grains of pyrite, while in the red surrounding rock none can be found. The conclusion is that the alteration has been produced by the reduction of the iron oxide in the rock to sulphide, and that this change has been effected by the percolation of waters along the fracture crevices. In the locality where this specimen

was found there are waters which carry at the present time sulphureted instead of carbonated waters, as the occurrence of strong sulphur springs in the Molly Gibson mine shows; other watercourses close by carry carbonated surface waters. In this case a rock which had been exposed to surface waters and had become considerably oxidized was by some slight change of currents made the channel of sulphureted waters, with the change which has been described.

The bleaching under immediate surface influences is best observed in actual outcrops, where it is most actively going on. It is especially well shown on a road on the mountain side to the south of Lenado. The weathered surfaces are altered to a light greenish yellow; and this

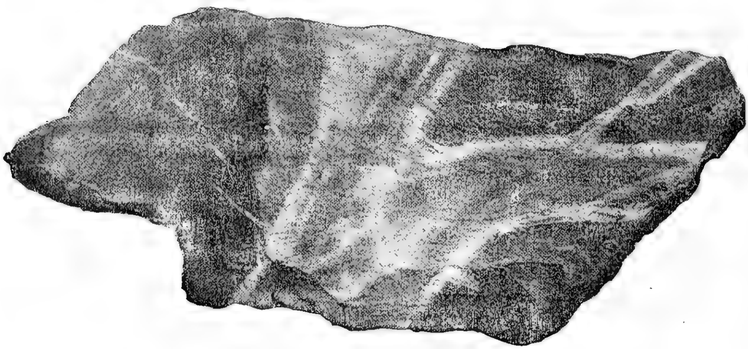

FIG. 2.—Zones of reduction in oxidized fine-grained dolomite.

alteration is also well marked along the joint planes, the alteration having taken place for an inch or so on both sides of the crack. The process is one which has been observed in the Maroon formation, also in the Triassic and in the other red-colored beds of the region; the microscope shows that it is essentially a withdrawal of the iron from the bleached rock. Carbonated surface waters, which take the iron into solution, are the probable agents.

Conditions of deposition.—The character of the basal bed of the Parting Quartzite series indicates deposition in water much shallower than that in which the dolomite sediments below were laid down, and in a position nearer the shore. Most of the coarse materials—quartz, feldspar, occasional mica, and tourmaline—are evidently the product of the erosion of granite,

while the dolomitic mud in which these fragments are embedded is probably detrital, and hence must have been derived from the subaerial erosion of some portion of the beds already formed. These things show that at the end of the deposition of the calcareous sediments of the Silurian a widespread but uniform elevation took place, so that those portions of the sea bottom which were nearest shore emerged from the waters and became dry land; after which the arenaceous sediments were deposited in the waters of a shallow sea. Inquiry into the origin of the smooth, delicately tinted lithographic dolomite which forms the distinguishing feature at this horizon gives further light as to the character of the sea. This rock is associated with the quartzite in the most intimate manner, alternating with it in successive small bands, thus showing that the two were deposited under very nearly the same conditions. Further, the cryptocrystalline dolomite often occurs in the quartzite in the form of nodules or masses of irregular shape, which are inclosed, like the quartz grains, in a cement of detrital dolomite of entirely different character. These nodules of lithographic dolomite inclose grains of detrital quartz similar to those in the rest of the rock, showing that either the d lomite was formed later than the deposition of the quartz or it was in a soft and plastic condition at the time of sedimentation. The occurrence, often only a few inches away, of narrow and continuous bands of the lithographic dolomite containing very little quartz, which alternate with the typical dolomitic sandstone or quartzite, proves that the two varieties of rock were contemporaneous in formation, and so the second alternative must be accepted. The occasional occurrence of this rock in irregular blotches and lenticular interbedded nodules, which resemble in form and habit flint nodules (see fig. 3), is another significant feature; and these things point to the origin of the rock as a direct chemical precipitate from the waters of the sea. Such a precipitation of calcite is now going on in many places, such as the Everglades of Florida, where shallow land-locked waters are exposed to evaporation. During such evaporation the carbonate of lime brought into the lagoons by the streams which enter them is gradually thrown down and accumulates on the bottom. It is probable that the lithographic dolomite was thrown down as such a calcareous precipitate, and that its dolomization was accomplished later on, under the same conditions as have been described for the underlying massive blue dolomite, and very likely at

the same time. From what little chemical examination has been made, it seems that the dolomization has not been so complete in the aphanitic dolomite as in the crystalline variety, a fact which may be explained by the closeness of texture of the former.

While the evidence shows that in many parts of this region there must have been an erosion interval between the deposition of the lower dolomite and that of the Parting Quartzite series, it is not clear whether such was actually the case in the Aspen district, although such an interval is suspected.

Correlation.—At Leadville there occurs at this same horizon a bed of quartzite separating the dolomite of the Silurian from that of the Carboniferous. Mr. Emmons[1] states that its thickness averages 40 feet, with a maximum of 70 feet, and gives it the name "Parting Quartzite." Since this quartzite, although differing somewhat lithologically from the intercalated quartzites and lithographic dolomites which are found at Aspen, is yet evidently their stratigraphical equivalent, occurring at the same horizon, being of the same thickness, and bearing evidence of deposition under closely similar conditions, the term "Parting Quartzite series" has been adopted for the formation at Aspen. Mr. Eldridge[2] has described what is also evidently the equivalent of these beds in the Crested Butte area, thus:

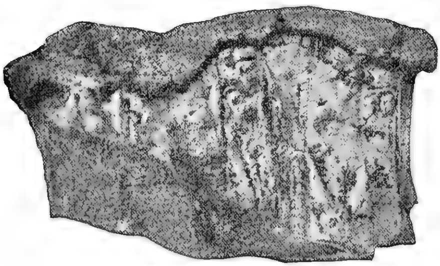

Fig. 3.—Nodule of lithographic dolomite in dolomitic sandstone.

> The upper division, 60 to 90 feet thick, consists mainly of green, yellow, red, and white shales, with more or less arenaceous and calcareous layers, the latter passing into thin limestones. The persistence of its general lithologic character renders this horizon easily recognizable.

Age of Parting Quartzite beds.—In the absence of fossils this series has been generally included in the Silurian beds, and the Devonian has been sup-

[1] Geology of Leadville: Mon. U. S. Geol. Survey. Vol. XII, 1886, p. 61.

[2] Geologic Atlas U. S., Anthracite-Crested Butte, folio 9, 1894, p. 6.

posed to be lacking. The Devonian beds of the Kanab Valley, however, as described by Mr. C. D. Walcott,[1] correspond closely with the Parting Quartzite series in nearly every detail, and afford very strong grounds for correlation. The Kanab Valley lies in southern Utah and northern Arizona, about 300 miles southwest of the Aspen district. Mr. Walcott describes the Devonian here as follows:

> The Devonian beds are very variable in character, and of little vertical range. At their greatest development, when increased by being deposited in a hollow of the limestone beneath, there is but 100 feet of purple and cream-colored limestone and sandstone, passing into gray calciferous sandstone above. Over the knolls of Silurian limestone the upper beds alone extend with a thickness of from 10 to 30 feet. The purple sandstones deposited in the hollows of the Silurian limestone are characterized by the presence of placoganoid fishes of a Devonian type. The Silurian limestone was extensively eroded antecedent to the deposition of the superjacent Devonian beds.

With very slight modifications this might be taken as a description of the Parting Quartzite series at Aspen. The "purple and cream-colored limestone and sandstone, passing into gray calciferous sandstone above" describes the deep-colored sandstones and shaly dolomites of Aspen, which pass upward into the heavier upper sandstone and quartzite. The evidence of the erosion interval between these beds and the underlying dolomites is also important in the correlation. At one locality in Aspen, on the side of East Aspen Mountain, overlooking the town, scales and teeth of fishes were found in the shaly beds directly overlying the dolomites. These fossils were examined by Dr. George H. Girty, who made the following report:

> The vertebrate fossils are fish remains, and evidently come from a bone bed. They consist of dissociated and fragmentary plates and bones, together with one tooth and a cast of another. As far as I have been able to ascertain, the latter belong to the sauroid fishes, and probably may be referred to the genus Rhizodus, Owen, or perhaps to the allied genus, Eusthenopteron. Rhizodus itself, in this country, occurs in the Carboniferous, both Upper and Lower, while Eusthenopteron is found in the Upper Devonian.

In the Kanab Valley section the sandstones and impure limestones of the Devonian are underlain by 185 feet of massive mottled limestone, with 50 feet of sandstone at the base, constituting the Silurian series, and are overlain by 735 feet of massive Carboniferous limestone, with arenaceous and cherty limestone above, passing upward into friable red Carboniferous

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[1] Am. Jour. Sci., Sept., 1880, 3d series, Vol. XX, p. 224.

sandstones. Thus the entire sequence of deposition is seen to have been remarkably like that at Aspen. Mr. Walcott observed evidence of a slight unconformity by erosion between the Devonian beds and the overlying limestones. Evidence of such erosion interval was not obtained at Aspen, but it has been observed by Mr. Emmons[1] between the Parting Quartzite and the overlying Carboniferous limestones on the East Fork of the Arkansas.

These grounds, therefore, are thought sufficient for placing the age of the Parting Quartzite series as probable Devonian.[2]

CARBONIFEROUS FORMATIONS.

LEADVILLE LIMESTONE.

Above the Parting Quartzite series there comes a heavy dolomite similar to the Silurian, which is in turn overlain by a massive blue limestone of quite different structure. This blue limestone is distinctly separated from the argillaceous and carbonaceous limestones and shales above, which belong to the Weber formation. The dolomite and the blue limestone are classified together as the Leadville limestone, the name being taken from the corresponding dolomitic beds at Leadville. Locally the dolomite and the limestone are known by the names of "blue and brown lime," from the circumstance that the dolomite contains a small quantity of iron, which, when oxidized, as in most of the rock near the surface, gives a general brown tinge, while the pure limestone retains its blue color. The thickness of the Leadville formation is comparatively uniform throughout the district, so far as observed, having an average of about 350 feet, of which from 200 to 250 feet are dolomite, and 100 to 150 feet are of blue limestone.

THE DOLOMITE.

Origin.—It has been a hotly contested question in Aspen, and one which has had an important economic bearing, whether the Carboniferous dolomite was originally deposited as such or became dolomized by subsequent action. Without going into details, it will simply be stated here that there is abundant evidence of two periods of dolomization, one of which occurred before

[1] Geology of Leadville: Mon. U. S. Geol. Survey, Vol. XX, p. 61.

[2] Since the above was written, additional fossils have been collected from the bed which has been mentioned above, by Mr. Tower, in the summer of 1896. These fossils were submitted to Mr. Charles D. Walcott, who pronounces them to be scattered and broken plates of placoganoid fishes and to be undoubtedly of Devonian age.

the deposition of the blue limestone, while the other was much later, and was closely connected with the ore deposition. There are numberless proofs of the latter process all through the Aspen district, especially in the more highly mineralized localities, where the blue limestone has been altered into dolomite in zones following faults or fractures which cut across the bedding of the limestone, or in zones following the bedding planes. It is also proved, however, that the great body of dolomite which forms the lower part of the Leadville formation was formed previous to the fractures along which the waters which effected the later dolomization ascended; for the contact of the dolomite and the limestone is faulted and broken by these fractures, exactly as the other sedimentary formations are.

Throughout the district the dolomite and the limestone maintain about the same relations and have about the same thickness and the same well-marked plane of separation, although in places this uniformity is obscured by faults, as is the case on the whole southern part of the district, from the Roaring Fork to Lenado, over which area the blue limestone is cut off by a fault which runs nearly parallel to the bedding. In Tourtelotte Park, near Castle Butte, is a locality where it was at first supposed that the dolomite was missing and that the blue limestone rested directly upon the Parting Quartzite series; but subsequently this appearance was found to be due to a fault. At Leadville the corresponding formation is entirely of dolomite, but has a thickness of only about 200 feet. In the Crested Butte district Mr. Eldridge gives a thickness of 400 to 525 feet, of which the upper 75 to 150 feet is a massive bluish limestone, while the rest is grayer and dolomitic. The lateral extent of this dolomite bed is therefore very great, and the stratigraphical distinction of the dolomite from the overlying limestone is persistent, at least throughout the Aspen, Crested Butte, and Anthracite districts. Such widespread lithological peculiarities can not be ascribed to any local metamorphism, but to some uniform widespread cause which acted before the deposition of the blue limestone, since this horizon shows none of its effects. The microscopic peculiarities of the Carboniferous dolomite are identical with those of the Silurian, and for the same reasons which have been enumerated in considering the origin of the Silurian it is probable that the lower 250 or 200 feet of the Leadville formation was deposited originally as a calcareous sediment, and that these sediments became dolomized subsequently, but before the deposition of the

blue limestone, through the action of magnesian salts, which were held in solution in the waters of a probably evaporating and shallowing sea that covered the whole district.

Description.—Where the Carboniferous dolomite has not suffered oxidation it is hard and gray blue in color, compact, and with a rough, conchoidal fracture. Such fresh rock, however, is found in large quantities only in the lower levels of some of the mines, such as the Free Silver and the Smuggler, in which, 700 or 800 feet below the surface, a depth is reached where the effects of oxidation have been little felt. In these mines the changes which one observes in the dolomite, going upward toward the surface, explain the whole process of alteration. The rock becomes yellowed by the formation of a small amount of iron oxide, which microscopic study shows to be probably derived from the oxidation of iron carbonate that is crystallized with the dolomite. The alteration of the carbonate to the oxide is accompanied by a decrease of bulk, and some dolomite is also probably carried away in solution by percolating carbonated waters; these withdrawals bring about concentration, which results in the formation of numerous joints. These joints become so close that when the rock is struck forcibly it often crumbles into many small, angular fragments. From its color the oxidized dolomite is called by the miners "brown lime,"[1] while from its close jointing it is called "short lime." These peculiarities are characteristic of the rock to a greater or less extent all over the surface and within the zone of active surface alteration.

Microscopic structure.—The structure of the Carboniferous dolomite is identical with that of the Silurian. The rock is made up of small, gray crystals of dolomite, interlocking, and with a constant tendency to rhombohedral form. These crystals are usually uniform in size, but sometimes they vary slightly in different areas, which change gradually one into the other. On oxidation they develop iron oxide along their edges and in cleavage cracks, showing that they contain a small percentage of iron carbonate. Quartz is always present in the same peculiar grains which have been noted in the Silurian dolomite, and which are easily taken for detrital grains, but which on close examination show by their fresh, unbroken structure and irregular outlines, as well as by the circumstance

[1] The term "brown lime" is rather promiscuously applied. It may refer to the dolomized limestone or to the blue lime, which has been greatly altered to a brown lime that is not dolomitic, but is a porous lime carbonate containing much iron. In this paper "brown lime," "short lime," and "dolomite" are synonymous.

that they are inclosed in crystals of dolomite, that they have formed subsequent to the deposition of the rock. These grains are often clustered in certain areas, displacing the dolomite and forming chert nodules and bands.

Chert.—The chert is generally dark gray in color, sometimes light gray. It is in seams, nodules, or bands, which usually follow the bedding, but occasionally, as on West Aspen Mountain, the seams follow a set of fractures which cut across the bedding, and so give a deceptive appearance of stratification.

Composition of Leadville dolomite.—Many analyses of the dolomite have been made by the mine managers of Aspen, who consider the determination of this rock an important aid in prospecting for ore; and these analyses have been supplied to the Survey by the courtesy of these gentlemen. The following eighteen show the respective proportion of oxide of magnesium and oxide of calcium in as many different samples. These were selected at random from the list, but care was taken to include only those which were from the dolomite stratigraphically below the blue limestone, and to exclude dolomite which is a local alteration of the limestone. This latter dolomite shows transitional stages from the limestone which are indicative of its origin, while the composition of the dolomite which everywhere underlies the blue limestone is nearly uniform. Following is the table:

Oxides of calcium and magnesium in Leadville dolomite.

CaO	MgO
33.4	23.2
30.46	20.9
31.7	16.57
32.5	17.72
34.9	15.62
31.7	15.83
31.6	17.80
31.3	19.20
37	13.29
34.2	12.97
30.2	20.80
31	20.60
30.4	19.46
32.2	17.90
30.9	20.40
31.3	17.83
35.2	16.21
30.9	20.4
Average 32.3	18.15

The average of all these analyses gives 32.3 per cent of calcium oxide and 18.15 per cent of magnesium oxide. Since they are taken from many parts of the district, their average may be accepted as the composition of the dolomite constituting the lower part of the Leadville formation.

Normal dolomite, according to Dana, contains 45.65 per cent of magnesium carbonate, and 54.35 per cent of calcium carbonate. This is equivalent to 21.74 per cent of magnesium oxide, and 30.43 per cent of calcium oxide. The Leadville dolomite of Aspen, therefore, contains somewhat more lime and less magnesium than typical dolomite. There is also nearly always present a small amount of silica and of iron. Not so many determinations of these ingredients were available, but from the average of several analyses of each it is found that the silica constitutes probably

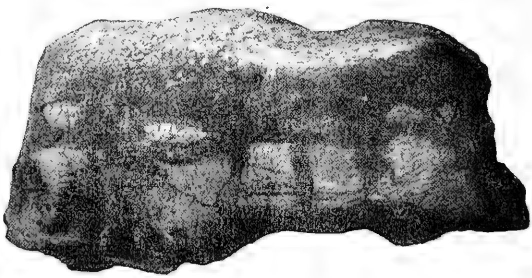

Fig. 4.—Sandstone veins in dolomite.

2 or 3 per cent and the iron oxide about the same. The iron oxide determined by the analysis, it will be remembered, is really in the form of carbonate in the unaltered rock. There is also often present a small amount of alumina.

Sandstone veins in dolomite.—Mr. Tower observed on Aspen Mountain irregular sandstone veins of small size in the dolomite. These veins were often conformable to the bedding, but were also found cutting vertically across the bedding and connecting with the horizontal veins, so that it was evident that they were of later origin than the inclosing rock. The finding of angular fragments of the dolomite among the material of the vein confirmed this conclusion.

The largest of the veins observed was only a few inches wide, and from that they grade downward in size, sometimes filling crevices which measure

only about a tenth of an inch, where a single quartz grain fills up the width of the vein. (See fig. 4.) These veins become most prominent on the weathering of the rock, as the sand grains resist corrosion more than does the dolomite. Under the microscope the large grains in the filling are seen to be mostly quartz. These quartz fragments are of varying size, rounded or subangular in shape, and without any assortment or symmetrical arrangement. There are also many grains of feldspar, which is sometimes fairly fresh, and sometimes is altered to a muscovitic aggregate. Angular fragments of dolomite identical with the wall rock are common, and vary in diameter up to an inch. These materials are inclosed in a cement of closely packed, minute, irregular grains of carbonate, which from its behavior with acids is probably dolomite. This dolomite, however, has not the structure of the crystalline dolomite of the wall rock, but is plainly fragmental in nature.

The sandstone veins are not widespread, and were observed only in a few localities, and there are not sufficient facts to prove their origin. It is certain, however, that they fill fissures which were formed after the dolomite was consolidated into its present condition; and since this filling has become indurated into a hard and compact sandstone, its formation was probably not extremely recent. The well-rounded quartz grains show that they had been considerably worn by aqueous action previous to being laid down, and also that water was the vehicle through which they were introduced into their present positions. There is, however, no positive trace of stratification among the materials, nor any sorting such as is often observed in water-laid sediments, but grains of all sizes are confusedly intermingled and lie in every position, with no observable parallel arrangement of their longer axes. It seems, then, that the deposition was not slow, but immediately succeeded the formation of the fissures, and that the materials were all introduced at the same time.

Mr. Diller[1] has described cases of sandstone dikes in California, which are developed on a remarkable scale in shale beds. These dikes present peculiar features which indicate that they are not sediments, but that the material was forced upward, mixed with water, from a lower horizon, and so filled joint fissures, and that the formation of these fissures and the injection of the sand were phases of earthquake action. Cases where such injections have actually been known to occur, as in the earthquake at Charleston,

[1] Bull. Geol. Soc. Am., Vol. I, p. 411.

are cited by Mr. Diller. Other occurrences of sandstone veins or dikes have been described by various writers, many of them referring their origin to sedimentation from above, in open fissures. Mr. Cross[1] has described some interesting sandstone dikes in granite in the vicinity of Pikes Peak, but does not offer any suggestion as to their origin. The sandstone veins at Aspen resemble some of the grits of the Maroon series, which lie several hundred feet above the Leadville dolomite, and are separated from it by the Weber shales and limestones, as well as the blue Leadville limestone; on the other hand, there underlie this dolomite the various sandstones, quartzites, and dolomites which have been described. While, therefore, there is not sufficient evidence for any definite proof, the conditions are equally favorable for the application of Mr. Diller's theory and for the theory that they were filled by waters which penetrated downward.

Worm tracks in dolomite.—A peculiar phenomenon, which excites much curious interest among the miners, is the occurrence in mine workings of fragments of hard blue dolomite riddled by small cylindrical cavities, which are at once recognized as wormholes. Such specimens are found in the Free Silver shaft.

In specimens which do not show this perforation a similar structure is recognized under the microscope. In cross section there appear irregularly rounded or curved, generally elongated areas, which are perfectly distinct from the main rock, as if cut out. These are filled with crystalline dolomite, coarser in texture than the rest of the rock. In every way these areas seem identical with the worm tracks which are not uncommon among the fossils of limestones and other rocks. They were evidently made at an early stage in the history of the rock, when it was still plastic, and the cavities thus produced were filled with vein calcite or dolomite. Where, as in the Free Silver shaft, the cavities are now found empty, it is probable that the filling has been dissolved out by circulating waters. On the walls of these holes there are often very small crystals of pyrite.

THE BLUE LIMESTONE.

Description.—The limestone which overlies the Leadville dolomite is blue-gray in color, sometimes dark blue; it occurs in massive beds, and the outcrop usually weathers light blue, with a smooth surface. The difference

[1] Bull. Geol. Soc. Am., Vol. V, p. 225.

in weathering makes it ordinarily easy to distinguish the limestone from the underlying dolomite in the field. The dolomite usually contains tiny chert areas or grains of silica throughout its whole mass; on weathering these project beyond the plane of the softer inclosing rock. This rough surface affords lodging for red, yellow, and brown lichens, while the smooth surface of the limestone is usually quite clean. The iron of the dolomite, which oxidizes on weathering, also constitutes another distinguishing feature in the outcrop

In the fresh rock the distinction is also easily made. The dolomite is made up of very small crystals of nearly uniform size, which give a frosty appearance to the rock; while in the blue lime the texture is varied, certain small areas being lusterless, while others show crystal faces much larger than those of the dolomite. In the mines the method of distinguishing the two rocks is to flash a candle on the specimen, when comparatively large glistening facets determine the limestone and many fine lustrous points the dolomite.

Microscopic structure.—Under the microscope the structure of the blue limestone is peculiar and uniform, except where it has been effaced by altering processes, such as dolomization, silicification, and ferration. The rock contains numerous tiny organic forms, chiefly Foraminifera, which are embedded in crystalline calcite. The tests of these organic bodies are of calcite, which differs radically from the coarse calcite in which they are embedded. Under low powers it appears quite amorphous; under high powers it becomes a dark translucent mass, with many dimly polarizing specks, which, however, are not large enough to be positively recognized as individual crystals. In most of the material no polarization whatever can be made out. The interior of the shells, however, as disclosed by the sections, is filled with crystalline calcite like that of the cementing material. Crystalline calcite thus makes up about three-fourths of the rock, while the cryptocrystalline or amorphous lime carbonate makes up the remainder. The tests average about one-fiftieth of an inch in diameter.

Dr. R. M. Bagg, of Johns Hopkins University, has kindly examined some thin sections of this limestone and finds the following types of Foraminifera:

1. Endothyra sp.
2. Nodosinella sp.
3. Textularia sp.
4. Bigenerina sp.
5. Valvulina sp.
6. Lagena sp.

The Nodosinella is near *N. priscilla* Dawson; the Lagena forms are near *L. parkerina* Brady; Textularia is similar in section to *T. gibbosa* D'Orb.; but none of these types admits of positive specific identification in cross sections alone.

Age.—In Leadville fossils are reported by Mr. Emmons which place this horizon in the Lower Carboniferous. At Aspen no further attempt to fix the age was made, on account of lack of time and because the determination already made is quite sufficiently established. Various Carboniferous fossils—brachiopods, crinoids, etc.—as well as the Foraminifera which give the peculiar character to the rock, are abundant in the blue limestone.

WEBER FORMATION.

Description.—Above the blue limestone, and separated from it by a distinct plane, comes a series of thin-bedded carbonaceous limestones and calcareous shales. The typical rock of this series is a black limestone, thin-bedded and aphanitic in texture. It has two mineralogical features which are secondary in origin, but which are peculiarly characteristic of this horizon—the occurrence of scattered or segregated pyrite and the presence of many small irregular veins of white crystalline calcite. The rock is usually somewhat dolomitic and locally becomes a true dolomite.

Near the lower part of the series the rock is slightly more massive, becoming often dark blue in color or gray on oxidation. It then somewhat resembles certain varieties of the altered blue limestone, with which it may sometimes be confounded in the field. This variety of the Weber limestone is found throughout a large part of the Hunter Creek and Lenado districts, where it occurs in contact with the Leadville dolomite. The contact, however, is along a fault which has removed the blue limestone throughout this whole area. Above this lower division the limestone becomes black, shaly, and carbonaceous, with local thin beds of impure coal. These shales change above to the micaceous, thin-bedded gray limestone which has been taken as the base of the Maroon formation.

The Weber limestones are easily attacked by altering agents. Thus they are altered by underground waters along faults and watercourses, becoming silicified and dolomized and changing in color to various shades of red, brown, and yellow. Where the Weber limestone is completely dolomized, as along fault planes and often in the vicinity of ore bodies, there may

result a brown dolomite or "short lime" which can not be distinguished from that formed by the dolomization of blue limestone. There is also a marked alteration observable throughout the whole zone of oxidation, which is apparently due to surface influences alone. In this zone the hard, firm, calcareous shale softens and loses some of its cohesion. In consequence of this softening, the bluish-black color of the shale becomes dead black; this is accompanied by a partial alteration of the calcite in the rock and in the veins to gypsum. This change is well seen in many deep shafts which go below the zone of oxidation and penetrate the Weber rocks at some point where they are not softened in the vicinity of a watercourse. In the Smuggler and adjoining mines these transition steps were especially noted, the soft black "shale" of the upper levels becoming, at a depth of 700 or 800 feet, a hard, black, argillaceous dolomite. The zone throughout which this softening extends is practically the same as that in which the oxidation of the Carboniferous and Silurian dolomites takes place and in which the alteration of the sulphides in the ores to sulphates, carbonates, and oxides begins.

Microscopic structure.—Under the microscope the Weber limestone is seen to be made up largely of cryptocrystalline carbonate, so fine in grain that no individuals can be distinguished, while some areas are more coarsely crystalline. The manner in which these latter areas occur suggests regeneration, or crystallization by the same agents which have produced the veins of white calcite which are so profuse. Certain forms suggest organic origin; some of these are marked by the crystalline carbonate above noted, while others are distinguished by the presence of much opaque, dark, nearly submicroscopic matter, which is probably carbonaceous and argillaceous. This carbonaceous matter is irregularly disseminated in the whole rock, to which it gives its black color. There are occasional small detrital grains of quartz and of zircon. The quartz in some of the sections is rounded, while in others it has assumed the form of long, slender crystals. Since the origin of this material is apparently detrital, the crystals are probably formed by the building on of new silica to the original irregular grains. Pyrite is present in small crystals, sometimes distributed with apparent uniformity through the rock, but oftener concentrated along some weak and more porous zone. In sections where the organic forms are found the pyrite is often unmistakably clustered in their vicinity.

The beginning of the process of oxidation is seen in these sections to be marked by the alteration of the pyrite to iron oxide. This oxide stains the rock, concealing the black color given by the carbonaceous material; and thus the red, yellow, and brown varieties of the Weber limestone, which are found outcropping and in mine workings near the surface, are formed. The more complete alteration, which produces from the firm, hard, thin-bedded limestone the soft black "shale," seems, judging from both microscopic and chemical examination, to be essentially a process of leaching. Much of the iron and of the calcite is removed by percolating waters, which, moreover, generally bring about complete dolomization of the remaining carbonate. The withdrawal of this material destroys the cohesion of the rock and causes it to assume a soft and plastic form; and analysis shows that the argillaceous materials are greatly concentrated by this removal of the more soluble constituents.

Conditions of deposition.—Evidence in certain parts of the Rocky Mountain region[1] shows that there was an important break between the deposition of the lower and the upper Carboniferous, or between the formation represented in the Aspen district by the Leadville blue limestone and the Weber carbonaceous shales. The Leadville dolomite was probably deposited in the waters of a shallowing sea, in accordance with the conclusions already stated. At the close of its deposition a subsidence took place, so that the water became purer and ceased to contain any excess of magnesia. The conditions under which the blue limestone was deposited were uniform. The locality was sufficiently remote from shore to be entirely unaffected by land sediments, and the water was comparatively deep. The deposits were made up mainly of the shells of marine organisms, chiefly Foraminifera. At the close of this period of quiet deposition a great upheaval took place, so that what had been sea became dry land. When this land became again submerged, sediments were evidently deposited in shallow seas near to land, and at a rapid rate. The carbonaceous material which is characteristic of the Weber formation, and which sometimes becomes so important as to form local seams of impure coal, is the remains of plant material which was brought down from the land and buried in the rapidly accumulating mud at that period. The first sediments consisted chiefly of materials worn from the preexisting sedimentary beds, chiefly limestones and dolomites.

[1] S. F. Emmons, Geologic Atlas U. S., folio 9, Anthracite-Crested Butte, Colorado, 1894, p. 1.

This accounts for the fineness of the mud and the widespread presence of magnesia. The first indication that the sedimentary beds had been worn away and the granite exposed on the land is the occurrence of mica scales and other detrital materials in the gray limestone which overlies the black carbonaceous limestones, and which has been taken as the base of the Maroon. The amount of granitic material rapidly increases from this point upward, till within a hundred feet or so it forms the chief and finally almost the only constituent in the sediments.

Thickness of the Weber formation.—The great Silver fault, which runs through most of the district, at a slight angle to the bedding, has the Weber limestone generally on its west side. Part of the formation has therefore been cut out by the faulting, but how much it is not always easy to ascertain. The most favorable places for measuring the thickness of the formation are at the southern end of the area of the Tourtelotte Park special sheet, on the west side of the Castle Creek fault, and from the northern end of the area of the Hunter Park sheet through that of the Lenado special sheet. In the former of these places the thickness is made somewhat uncertain by the existence of an unknown number of small faults consequent upon the Castle Creek fault, and forming only a small angle with the bedding planes. In the latter place the presence of the Silver fault renders the measurement dubious. So far as can be judged from the character of the rocks, however, we have in both these places a tolerably complete section, and measurements show that the maximum thickness can not be much less than 1,000 feet.

MAROON FORMATION.

Above the Weber formation comes a great thickness of mixed arenaceous and calcareous sediments, forming impure grits and thin-bedded shaly limestones. This formation is calcareous and thin bedded at first, but becomes more massive and arenaceous farther up. The general color is a peculiar dark red, which has been characterized by different geologists in various parts of the region as chocolate red, venetian red, purplish red, and maroon. The formation as existing in various parts of the Rocky Mountain region has been described by the geologists of the Hayden Survey;[1] as found in the Mosquito district it has been described by Mr.

[1] Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873, pp. 18, 105; 1874, p. 114.

Emmons[1] under the head of "Upper Coal Measures," while Mr. Eldridge[2] has described it under the name of the "Maroon conglomerate." Although the series in the Aspen region is not conglomeratic, yet its lithological peculiarities show conditions of deposition nearly similar to those of the corresponding rocks of the Crested Butte district, and so the name "Maroon formation" has been adopted. Fossils discovered in these beds in various parts of Colorado show the whole series to be of Carboniferous age. Plant remains gathered by Dr. Peale[3] were referred by Professor Lesquereux to the Permian, while in the Tenmile district Mr. Emmons reports many fossils of Coal Measures types. In the Crested Butte district Mr. Eldridge found fossils in the limestone pebbles of the conglomerates which belong to the Coal Measures types. No fossils were found in this series in the Aspen district.

The purplish-red beds pass upward into more massive and finer-grained sandstones, which are more purely siliceous in composition and of a bright brick-red color. This formation is well marked throughout a large part of the Rocky Mountain district, and although fossil evidence is very scanty, it has been referred by most geologists, on broad and general grounds, to the Triassic. The change to these red beds, however, is not abrupt, and does not indicate any break in the sedimentation.

Description of the Maroon formation.—The gray calcareous member which has been taken as the base of the Maroon series is distinguished from the underlying rocks of the Weber formation chiefly by the absence of carbonaceous matter and the greater coarseness of its materials. It is essentially a very impure limestone, becoming sandy and micaceous in bands. Its color is in general gray, which becomes yellow, brown, or red in spots and nonpersistent bands. In some parts there are found intercalated green or blue thin-bedded limestones or calcareous shales. This gray bed is well marked from the vicinity of Smuggler Mountain northward to the limit of the Lenado special map. Its contact with the Weber shales is exposed in a knoll not far from the Smuggler shaft. It is shown in section in the Cowenhoven tunnel, and outcrops through most of the distance across the Hunter Park special area, near the road running from

[1] Geology of Leadville: Mon. U. S. Geol. Survey, Vol. XII, 1886, p. 69.
[2] Geologic Atlas U. S., folio 9, Anthracite-Crested Butte, Colorado, 1894.
[3] Annual Report of the Hayden Survey, 1873, p. 105.

Aspen to Lenado. Its thickness was measured in the Bimetallic tunnel at Lenado, where it is not complicated by faults, as in the Cowenhoven tunnel, and was there found to be approximately 200 feet. It is, however, variable, for the gray color sometimes extends up into the overlying calcareous standstones, so that these are included in the formation. This color is not always, perhaps not usually, original, but is the result of bleaching in rocks which have once been colored. Cases of this were noticed in the exposures in Hunter Park, where the brown calcareous sandstones which immediately overlie the basal gray limestone were bleached for a short distance on each side of fracture planes to a gray color. Microscopically this rock is made up of cryptocrystalline calcite, with considerable crystalline quartz in irregular grains, and crystals of gypsum and of pyrite. The texture is porous and the pores are irregular in shape.

Above the basal gray bed the rocks are practically the same throughout the whole thickness of the formation, except that toward the bottom there are rather more thin limestone beds than at the top. The prevailing rock is a dark reddish-brown, impure, micaceous sandstone, thin-bedded, and often shaly; in the more massive portions cross-bedding may ordinarily be observed. This sandstone passes by easy transitions, vertically and also laterally, into various allied but distinct rocks, which form beds of slight thickness. Most important among these rocks is a gray grit, which is made up mainly of quartz, mica, and feldspar, all being evidently derived from the disruption of granite. On the one hand this passes into a fine conglomerate and on the other into a light-gray, often reddish, micaceous sandstone or fine grit. Generally associated with the grits, but sometimes occurring in isolated beds in the brown sandstones, are other rocks—shales, generally red, sometimes green, which are transitional from the sandstones, and various types of green and blue limestone. These shales and limestones, however, make up a very small part of the rocks. Probably nine-tenths of the formation consists of thin-bedded brown sandstones, while four-fifths of the remainder is made up of gray grits and fine conglomerates. There is no massive light-red sandstone in the series, so far as observed.

Microscopic structure.—Under the microscope the gray grits are found to consist almost wholly of granitic material—quartz, feldspar, and mica,

with the accessory materials. In the coarser varieties of the rock there is very little indication of water action, the fragments being large and angular, and the different minerals being present in about the same proportion as in granite. There is always, however, a parallel arrangement of the flakes of mica, which shows that they were deposited in water. In the slightly finer varieties there is a more distinct sedimentary structure, and a small amount of calcite is present, probably detrital. Zircon and magnetite are present in rounded grains, and crystals of specular iron and of red hematite, probably secondary, are common. The mica is sometimes green, sometimes colorless; the green variety becomes colorless by a process of bleaching. The iron thus removed from the biotite has probably gone to form the crystals of hematite.

From this rock to the finer dark-red sandstone there are many transitional stages. The red sandstones differ from the gray grits in being of finer grain, in containing more calcareous and less granitic material, and in the appearance of certain new minerals. Quartz and feldspar, chiefly microcline, with mica, are present in about the proportion in which they are found in granite. The quartz is always fractured and cracked, as in granite, and the feldspar is sometimes fresh, but usually more or less altered to muscovite and kaolin. The mica is either green and pleochroic or colorless and without pleochroism. Much of the colorless mica is undoubtedly muscovite, but the production of a colorless mica by the bleaching of biotite is a process which can be observed in all its stages. The iron which is separated out in this process at first concentrates along the cleavage of the biotite, and afterwards is leached out and disseminated in the rest of the rock as earthy hydrated oxide, giving the red color to the rock in the field. In some areas the beginning of concentration of this earthy oxide into the crystalline form is seen; this is essentially a bleaching process, so far as the resultant color of the rock is concerned. Among the minor detrital materials which are derived from the abrasion of granite are zircon, apatite, tourmaline, and magnetite. In many of the sections the magnetite is many times more abundant than in the granite, indicating a concentration of this mineral by wave action, such as at present produces the magnetic sands on our shores. There are also detrital grains of limestone or dolomite. A widely distributed mineral is glauconite, in small, irregular grains. This is generally fresh, or shows the beginning of oxida-

tion, a process which is characterized by the formation of small translucent plates of red hematite somewhat uniformly throughout the mineral. There is a cement, more or less abundant, of fine, calcareous material, apparently detrital in nature.

The limestones and lime shales differ again from these sandstones only in containing a still smaller proportion of granitic materials and a correspondingly increased amount of calcareous material. In nearly every section almost all the commoner minerals which are ordinarily found in granite are present, tourmaline, zircon, and magnetite being especially persistent. These materials are embedded in a very fine-grained calcareous cement, which has the appearance of having been deposited as a lime mud. The green color of the limestones and shales is due to the presence of glauconite, which is often abundant, in green and brownish-green grains.

TRIASSIC FORMATIONS.

RED SANDSTONES.

Lenado Canyon affords a continuous section of the rocks from Lenado westward to where the sequence is interrupted by the Castle Creek fault. The junction of Weber and Maroon occurs at Lenado; the brown sandstones begin at the mouth of the Bimetallic tunnel and continue for a long distance down the stream, which here flows nearly at right angles to the strike, thereby affording a complete cross section. At a point about halfway from Lenado to the Castle Creek fault there is a marked though not abrupt change in the appearance of the beds. The sandstones become more massive, though they are still often thin bedded; and the prevailing color changes from dull reddish brown to light red. There are still occasionally thin limestone bands; but the red sandstones predominate, and the aspect of the outcrops is distinctly changed. There is a similar change in the beds in the more southern part of the district examined, although here it is not so distinct, and the upper red series appears to be thinner bedded. This upper series of more massive and lighter-red sandstones has been provisionally assigned to the Triassic period. It extends from the rather indefinite plane described above up to a series of thin-bedded sandstones and shales which correspond to the Gunnison formation of Mr. Eldridge[1] and which have been by him assigned to late Juratrias time. No fossils have been found in this red sandstone formation, for the conditions of deposition were not

[1] Geologic Atlas U. S., folio 9, Anthracite-Crested Butte, Colorado, 1894.

favorable to the preservation of animal remains; and as the same conditions prevailed throughout a great part of the Rocky Mountain region, the entire fossil evidence at this horizon is extremely scanty. It has been hitherto believed, however, that these beds belong to the Triassic. The Triassic was recognized in the vicinity of Aspen by the geologists of the Hayden Survey, although the sandstones on Woody Creek, mentioned above, were included in their maps with the Carboniferous. In the Crested Butte district the Triassic appears to be wanting, though it may be so altered as to be unrecognizable.

Microscopically these rocks are essentially fine-grained, impure sandstones with much ferruginous material. The thickness of the Maroon and the Triassic together can not easily be ascertained, on account of the disturbances which have taken place, and especially on account of the Castle Creek fault, which prevents the obtainment of any continuous section. It is therefore difficult to say how much the thickness varies in different parts of the limited area mapped; but from various sections a mean thickness for both formations of about 6,600 feet was obtained, of which the Maroon beds take up 4,000 and the Triassic 2,600 feet. These are the thicknesses which have been shown on all the sections.

Conditions of deposition of the Maroon and Triassic beds.—The lithological characters of the entire Maroon series show that it is derived almost wholly from the disintegration and rapid erosion of a granitic land mass. The rocks are made up in large part of this granitic material—quartz, feldspar, and mica chiefly, with some material derived from the limestones and dolomites which had previously been deposited. Mingled with this detrital material is some that is probably organic; of this class is some of the cryptocrystalline calcite. A mineral which is also of organic origin, and which is significant of the conditions of deposition, is glauconite. This mineral is found rather in the finer-grained and more calcareous beds than in the purely granitic strata, showing that its formation was in water slightly deeper than that in which the rest of the beds were deposited. The zone at which this mineral is ususally formed is that of the outer edge of the land-derived sediments. On the other hand, some of the grits are of nearly pure granitic material, very little worked over by water action; these were evidently deposited close to the shore.

In the Crested Butte area the corresponding Maroon beds are typically

conglomeratic, thus showing a still closer relation to the main land mass. The similarity of the beds at the top and the bottom of the Maroon series indicates the duration of similar conditions of deposition for a long period of time, although the prevailing coarseness of the sediments indicates rapid erosion and sedimentation. To account for such prolonged rapidity of erosion and such similarity of deposital conditions, we may suppose a land area which was very mountainous and a gradually sinking shore line, the subsidence of which kept pace with the building up of the beds. The change from the coarse and varied Maroon beds to the more uniform red sandstones of the Triassic shows a slight though well-marked change. As in the Maroon beds, however, the continued uniformity of the Triassic sandstones, which are similar from top to bottom, shows the continuation of the gradual subsidence which has been noted for the underlying beds.

The greater fineness of grain in the detrital material, however, and the greater purity (for the Triassic sandstones consist mostly of quartz sorted by wave action), indicate a less but still noteworthy amount of erosion, a change which may be explained by the gradual degradation of the land. The encroachment of the sea upon the land, which has been inferred from the lithological composition, is proved by the overlapping of the red Triassic sandstones upon the granite in a large part of Colorado.[1]

GUNNISON FORMATION.

Above the deep-red sandstones comes another series of beds with distinct and persistent lithological characters. This series consists of a gray or yellow basal sandstone, often calcareous, overlain by reddish, grayish, or variegated shaly sandstones. The thickness of the sandstone is about 50 to 75 feet, and that of the shales above averages perhaps 225 or 250 feet. These beds are well exposed on the side of Red Butte, where they are inverted; and also on the west side of Maroon Creek, where they are in their normal position.

On Red Butte much of the variegated appearance of the beds has been found to be due to a bleaching process analogous to that which has already been mentioned. The normal color of the beds appears to be a red brown, a little lighter than the typical color of the Maroon formation. There are

[1] Hayden, Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1874, p. 44; A. R. Marvine, Ann. Rept. U. S. Geol. and Geog. Surv. Terr., 1873, p. 142.

occasional interstratified limy beds. The formation is broken up by profuse, irregular jointing in many places, so that the outcrop is very friable. In these places the red rock becomes mottled with gray, although there is no apparent difference between the gray and the red portions except the color. Often these gray spots mottle the rock thickly; often they are arranged in bands parallel to the stratification; and often they unite so as to form a continuous seam. At one locality there was observed a system of fractures at right angles to the stratification, and the gray bands follow these fractures to the exclusion of other parts of the rock; the gray color penetrates for varying but always slight distances from the crevice. By a combination of these phenomena an irregular patch of gray 4 or 5 feet in diameter is formed in places in the red rock. These occurrences show that the gray is derived from the red by the removal of iron; the probable agent is carbonated surface waters, which penetrate along fractures and porous areas, dissolve the iron, and carry it away.

Under the microscope this red shaly sandstone is seen to be very fine grained and to be made up mostly of very small grains of detrital quartz, with altered ferruginous materials, apparently detrital, which can not be exactly determined. These minerals are inclosed in a plentiful cement of calcite, which is in places finely granular and in other places without recognizable crystallization. There are also flakes of gypsum. The red rock is colored by earthy iron oxide disseminated throughout the rock; and the gray part differs from the red only in the absence of most of this oxide, so that only slight yellow stains are left. The transition from red to gray is gradual, as seen under the microscope, but takes place within a short distance.

This formation, consisting of the basal sandstone and the overlying shales or shaly sandstones described, and having an aggregate thickness of approximately 400 feet, is the stratigraphical and lithological equivalent of the Gunnison formation of Eldridge,[1] as described in the Crested Butte area. Mr. Eldridge assigns this formation to late Juratrias age, basing his correlation on its stratigraphical and lithological equivalence to the Atlantosaurus beds of the eastern side of the Rockies and the similarity of the molluscan fauna found in the two localities. The fossils described by Mr. Eldridge in the Crested Butte district were fresh-water forms, showing that

[1] Geologic Atlas U. S., folio 9, Anthracite-Crested Butte, Colorado, 1894.

the beds were deposited in fresh-water lakes; and this conclusion probably holds good of the formation in the Aspen district.

CRETACEOUS SERIES.

DAKOTA FORMATION.

Lying above the Gunnison formation, as exposed on Red Butte and on Maroon Creek, is a massive white sandstone which has been recognized in this same stratigraphical position in many parts of the Rocky Mountains, and which has been found from its fossil remains to belong to the Cretaceous. To this has been given the name Dakota formation. The sandstone varies in color from white to grayish and pinkish; often it becomes fine grained, and in bands is gritty and conglomeratic, and not only quartz, but feldspar and other granitic detritus can be observed in the coarser parts. In the upper part of the formation the rock is finer grained and contains abundant plant remains, which, however, on account of the porous nature of the rock, are not well preserved. Locally the rock becomes a quartzite, the secondary cementing silica being often distributed in irregular bands and lenticular areas in the sandstone; frequently it is found only in irregular bunches, so that there are nodules of quartzite in the sandstone. These nodules become conspicuous on weathering, since they resist erosion better than the sandstone.

The average thickness of this sandstone, taken from various measurements, is about 250 feet.

COLORADO FORMATION.

The two divisions of the Colorado formation—the Fort Benton shales and the Niobrara limestone—are both recognizable in the Aspen district.

Benton shales.—Above the Dakota sandstone comes an estimated thickness of 350 feet of black calcareous shales, with some thin-bedded and shaly limestones. These shales are best exposed on the west side of Red Butte, where they are inverted. From some thin-bedded limestones in the upper part of the formation fossils were collected which were identified by Mr. T. W. Stanton as *Gryphæa newberryi* and *Ostrea lugubris*.

Niobrara limestone.—Above the Benton shales comes a bed of dense gray or blue limestone with a close texture and conchoidal fracture, which is persistent throughout the district. This formation is well exposed in the bed of Maroon Creek at two points, one at Red Butte, near the junction of

Maroon Creek with Roaring Fork, and another half a mile or so up the creek from the butte. This limestone is from 50 to 75 feet thick, and is overlain by thin-bedded shaly limestones, which pass upward into the soft gray or black shales of the Montana formation. On Red Butte the dense limestone itself is somewhat fissile, which doubtless arises from the squeezing to which it has been subjected in the formation of the overturned fold that is exhibited here; but in the outcrop farther up Maroon Creek it is more massive. This limestone is a close lithological as well as stratigraphical equivalent of the Niobrara limestone of the Crested Butte area, and its correlation is based chiefly on this equivalency. In the Crested Butte area Mr. Eldridge found fossils which indicated its Niobrara age, and the occurrence at this horizon of a limestone similar to the one described is widespread in this region.

The average thickness of the Niobrara in the Aspen district may be taken at about 100 feet. The line of division between the upper shaly beds of the Niobrara and the overlying Montana shales is not distinct.

MONTANA FORMATION.

Above the Niobrara comes a very great thickness of gray or black shales, generally carrying thin bands or lenticular masses of impure black limestone. Some of the limestone beds and lenticular bodies are partly silicified. The main outcrops extend down Roaring Fork from Red Butte to the border of the area mapped, a practically continuous exposure being afforded along the banks of the stream and in the cut which has been made for the railroad, and also up Maroon Creek from Red Butte for half a mile, passing across the overturned syncline to the underlying Niobrara limestone. The upper part of the formation, which occupies the greater part of the space between the Roaring Fork below Red Butte and Woody Creek, is mostly concealed by glacial detritus, so that no close examination could be made. From the nature of the drift, however, and from occasional doubtful outcrops, it seems probable that the upper part of the series becomes slightly more arenaceous. The two subdivisions which the term Montana covers—namely, the Fort Pierre and the Fox Hills—can not, however, be well distinguished in this area In thin limestone layers ranging from below the middle to near the top of the formation were found great numbers of fossils, identified by Mr. T. W. Stanton as *Inoceramus barabini.*

The thickness of this formation, as nearly as could be estimated under the unfavorable conditions, is approximately 4,000 feet.

LARAMIE FORMATION.

On the comparatively low ridge on the left side of Woody Creek, near the point where the stream emerges from the canyon, a heavy bed of pure white sandstone outcrops on the west side of the Castle Creek fault, becoming yellowish or reddish in places, and forming a bench about 100 feet high. This has been taken as being about the base of the Laramie formation.[1] Below it, on the hillside, a shaft which has been sunk for prospecting purposes shows a few feet of solid blue limestone of very fine texture. Above this white sandstone come beds of impure brown and green sandstones, thin-bedded and friable, often micaceous and shaly. These carry abundant plant remains, which, however, are not sufficiently preserved to admit of identification. The series is lithologically like that of the coal-bearing Laramie in the Crested Butte and Anthracite regions, but no coal seams were noticed in the Aspen district, although some of the layers in the impure sandstones above described carry such a quantity of plant remains as to become very black and carbonaceous.

These basal beds of the Laramie form a synclinal basin against the Castle Creek fault; outside the rim of this basin the outcrops of the Laramie sandstones give place to the underlying Montana rocks. The Laramie, therefore, occupies but a limited area, and only the lower portion of the beds is exposed, the whole upper part having been removed by erosion The actual thickness of the formation as shown here is probably about 500 or 600 feet

The Laramie beds are the youngest rock formations exposed in this district, with the exception of the Glacial and post-Glacial formations, which will be considered separately.

PRE-CRETACEOUS UNCONFORMITY.

At the close of the formation of the red Triassic sandstones a marked break in sedimentation occurred in this and the adjacent districts. This break was probably accompanied by a considerable uplift, for the succeeding beds of the Gunnison formation, which are of late Juratrias age, are

[1]Annual Report of the Hayden Survey, 1874, p. 35.

probably of fresh-water origin. In the interval between the deposition of the red sandstones and the Gunnison sandstones and shales there was probably some folding and perhaps a great amount of erosion. The red sandstones appear to be missing in part or wholly in certain areas which closely adjoin the Aspen district.

This uplift was followed by a depression, so that the Cretaceous beds above the Dakota are of marine formation, through the Fort Benton, Niobrara, Montana, and a large part of the Laramie. The greater part of these marine sediments, as illustrated by the thick Montana shales, were deposited in comparatively quiet waters, and were derived from a land surface which was being actively, but not enormously eroded. At the top of the Cretaceous section there recur beds of sandstone, at first intercalated at wide intervals in the shales, but finally forming beds of greater purity and thickness. These indicate an elevation corresponding to the preceding depression. This elevation, further carried on, is shown by the fresh-water deposits of the late Cretaceous, and culminated in the violent uplift and volcanic disturbance toward the close of the Cretaceous and the beginning of the Tertiary.

CRETACEOUS-TERTIARY UNCONFORMITY.

Near the close of the Cretaceous, in the Laramie, there began a series of disturbances which has probably lasted up to the present day, although the amount of disturbance has varied considerably at different times. This disturbance toward the close of the Cretaceous was manifested by the lifting above the sea of the whole mass of the Rocky Mountains in Colorado; and as if this uplifting were accompanied by the accumulation of molten rock beneath the earth's crust, at intervals great masses of lava were thrust upward into the sedimentary rocks, or were poured out on the surface. The dynamic strains which arose in this disturbance were relieved partly by folding of the rocks and partly by faulting. The main uplift of the Rocky Mountains, producing the lofty structures which excite our admiration at the present day, began at this time. The greatest disturbance seems to have been about at the end of the Cretaceous and the beginning of the Tertiary; the existing Tertiary beds were deposited after this maximum disturbance, and therefore lie unconformably upon the folded Cretaceous strata. Such Tertiary beds are not found in the Aspen district; but to understand the history of the

important disturbances which are manifested in the rocks of this district it is necessary that this episode should be understood.

INTRUSIVE ROCKS.

There are two distinct varieties of intrusive rocks in the Aspen district, a quartz-porphyry and a diorite-porphyry, both usually much altered.

DIORITE-PORPHYRY.

Habitus.—This porphyry is a dark-green, fine-grained rock, showing much decomposition, even to the naked eye. It occurs chiefly, so far as the limits of the Aspen region go, in the form of a single sheet, which has the usual characteristics of interbedded sheets in the Rocky Mountains. It is in a general way parallel to the bedding of the sedimentary rocks in which it has intruded itself, so that in any very limited area it appears as a simple interbedded sheet; when followed along the strike, however, it is found to cut across the beds at intervals, usually at a slight angle, so that it is only by its position relative to the various sedimentary beds that any change is noticeable. This single sheet of porphyry is found on the southern border of the Tourtelotte Park special area (which was the southern limit of the present examination), at about the horizon of the Parting Quartzite series. Here it has a maximum thickness of about 150 feet; it frequently cuts across the Parting Quartzite, or surrounds it so as to conceal its outcrop. This sheet can be traced from here toward the north nearly continuously on the bare hilltop; it takes a position permanently below the Parting Quartzite series, and gradually cuts lower down into the Silurian dolomite. Just before reaching the area included in the special map of the Tourtelotte Park mining district, it cuts down across the formation a little more sharply, and near the southern end of this map it enters the Cambrian quartzite From here its outcrop shows that it still cuts downward toward the north, till on Aspen Mountain it lies at the very base of the Cambrian. On West Aspen Mountain, the most northerly point at which it has been found, there is only 5 or 10 feet of conglomeratic quartzite between the porphyry and the granite, and on East Aspen Mountain it is found in contact with the granite In a lateral extent of 3½ miles this sheet therefore cuts across the formation 500 or 600 feet, always downward to the north.

There is also a gradual thinning of the sheet toward the north. Its maximum thickness of 150 feet at the southern limit becomes 30 to 40

feet at the northern limit of the Tourtelotte Park special area, and this is reduced to 15 or 20 feet at the northern end of Aspen Mountain. This thinning ends in the ultimate disappearance of the rock, for it is not found on the other side of the valley, north of Aspen.

There is also a noticeable thinning of the sheet from the east toward the west. While the outcrop of the bed seems to be practically continuous on the east side of the mountain spur which lies between Roaring Fork and Castle Creek, so far as can be determined in view of the subsequent complicating faults, there are on the west side places where it not only thins out but entirely disappears for a short distance, only to reappear farther along on the same horizon. It has thus on this western slope the character of an intermittent sheet.

Description.—Very little of the internal structure of the rock can be made out with the naked eye. It is always fine grained, dark green in color, and uniform in appearance. Occasionally phenocrysts of darker green than the groundmass, and having the habit of hornblende, are present. There are also occasional feldspar phenocrysts, small and profoundly altered around the edges, so as to present an irregular shape; and crystals of pyrite are sometimes present. In texture the rock is granular and slightly porous.

Microscopic structure.—Under the microscope it is seen that the rock has always a porphyritic structure, although the phenocrysts are of small size, and the structure might easily change to granular. The phenocrysts are always much altered, often so much so that none of the original mineral remains. The most common form is a collection of alteration products which form pseudomorphs after hornblende. These pseudomorphs are primarily of chlorite; further alteration has brought about the formation of secondary quartz, epidote, carbonates, and limonite. No unaltered hornblende was found in any of the sections examined. Biotite is also common among the phenocrysts, often completely altered like the hornblende, chiefly to chlorite, but often having residual areas of green or brown mica, which frays out along the edges to chlorite. Feldspar crystals are common, usually more or less completely altered to muscovite and calcite; these seem to be mainly orthoclase, although some show the multiple twinning of plagioclase. In a peculiar phase of the rock found in contact with the granite on Aspen Mountain there occurs a feldspar

which is entirely altered to epidote, with some associated quartz. As there are in the same section feldspars having the more usual alteration above described, this must be a different variety, probably a plagioclase very rich in lime—anorthite (?). Quartz is common as a decomposition product of the phenocrysts, and occasionally becomes so prominent as to make up the larger portion of the pseudomorph. In one section, however, a quartz crystal, which appeared to be original, was found among the pseudomorphs. A constant and striking mineral, apparently original, is ilmenite, which in the sections examined is always present in remarkable profusion. This has crystal form and shows cleavage. It alters occasionally in a limited degree to a blood-red, translucent oxide—red hematite (?)—but usually to the milky opaque alteration product known as leucoxene. Magnetite also occurs in crystals as an original constituent; pyrite occurs sporadically, and is probably secondary. The groundmass in which these minerals are set is moderately fine grained and granular; its constituent minerals are chiefly feldspar, both orthoclase and plagioclase, and quartz.

Porphyry dikes.—In two localities in the district examined small dikes of greatly decomposed rock, which, however, appeared to be the same as the rock of the more persistent sheet, were found. One of these localities is in the Tourtelotte Park special area, where a small dike was noticed in the Silurian dolomite, above the main sheet; the other is on Maroon Creek, where a dike a few feet wide was seen cutting the Triassic sandstones.

Source.—The marked thickening of the sheet of porphyry toward the south and its disappearance toward the north point out the direction from which the intruding rock was propelled. From the southern edge of the district in which detailed mapping was carried on the sheet was not continuously followed southward, but at several points toward the south it was observed, always thickening, and it undoubtedly runs into the great diorite mass of Castle Peak, some 10 miles away. Castle Peak is made up mostly of complex dikes and intercalated sheets of eruptive rocks in the Maroon Carboniferous beds. To the south this complex soon changes to the solid diorite, as shown in the adjacent White Rock Mountain, which is a part of the great cross-cutting body of diorite found all along the axis of the Elk Mountains, and whose advent was one of the chief phenomena connected with the formation of that range.[1]

[1] Whitman Cross, Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1894, p. 179.

The diorite of Castle Peak and White Rock Mountain differs only slightly from the rock which on the map of the Aspen district has been named a diorite-porphyry. The Elk Mountain diorite, of which Castle and White Rock peaks furnish examples, is, according to Cross, a fine and even grained rock, characterized by a nearly equal development of hornblende and biotite, with some quartz and local augite. The Aspen diorite-porphyry differs from this granular rock chiefly in structure, being finer grained and possessing a weakly developed porphyritic structure. These peculiarities of crystallization, which in some of the sections examined show a tendency to disappear and to merge into the nonporphyritic or granular structure, are amply accounted for by the conditions under which it crystallized—in a thin sheet at some distance from any large mass of heated rock. Miners and others who have frequent occasion to mention the rock in everyday life will do well to call it "diorite," and thus avoid confusion with the quartz-porphyry which occurs in the same district and which belongs to a quite distinct type. This rock has been intruded into the Aspen district from the south, the intrusive flow cutting down slightly across the bedding, and it is undoubtedly an offshoot of the great diorite mass of the Elk Mountains.

QUARTZ-PORPHYRY.

The quartz-porphyry of the Aspen district is easily distinguished from the diorite-porphyry in the field by its nearly white color, which may be changed to brown or yellow. It shows very few phenocrysts, and has a groundmass which is aphanitic to the naked eye. It has a close resemblance, both in the field and under the microscope, to the White Porphyry of Leadville.

Habitus.—The porphyry occurs chiefly as a sheet which is approximately conformable to the bedding of the sedimentary rocks in which it occurs, but which locally cuts across the bedding. This sheet is always, in the Aspen district, at a higher horizon than that of the diorite-porphyry, being usually near the base of the Weber shales, so that the two rocks do not come in contact. A great number of faults have occurred since its intrusion, which, with the after-effects of erosion, have operated to remove portions of the sheet, so that its original distribution can not always be closely observed. Its thickness on Aspen Mountain, however,

probably reaches 400 feet or more. Toward the south, in Tourtelotte Park, it seems to be somewhat thinner, the average thickness being about 250 feet. Near the south end of the park the sheet cuts upward across the shales and is not found at the lower shale horizon farther south. The northerly pitch of the formation, combined with faulting, brings lower beds to the surface immediately south of this point, so that neither shale nor porphyry is exposed on the east side of the Castle Creek fault, from here to the southern end of the district. On the west side of the Castle Creek fault, however, the same porphyry appears in Ophir Gulch, and from there runs nearly continuously to the southern edge of the area mapped, occupying the same geological position as on Aspen Mountain and in Tourtelotte Park—near the bottom of the Weber shales. Its thickness has been estimated and mapped in this region as varying from about 300 to 450 feet, but, on account of the numerous parallel faults which belong to the Castle Creek system, it is by no means certain that this estimated thickness is correct. From here to the south it has not been traced, but has been noticed at various points; it seems to thin out and disappear, however, somewhere near and to the west of Ashcroft, after crossing Castle Creek about 2 miles below that village.

Northward from Aspen Mountain the extent of the porphyry is concealed by a fault which traverses the country, with a trend that diverges but little from the strike of the beds, and which cuts off more and more of the sheet toward the north. In this way the porphyry becomes very thin in the Smuggler mine, and is last found as a permanent sheet in the southern part of the Della S. mine, where it thins out between the fault below and the shales above; northward from this there are bowlders and fragments of porphyry in the fault breccia, but the continuous sheet does not reappear. What the original extent of the sheet previous to faulting may have been is therefore hard to determine. In Hunter Park, however, it has been inferred from the minor lithological features of the Weber rocks, and from their thickness, that nearly the whole series came to the surface on the west side of the fault; and since throughout this district there is no porphyry, it is possible that the original sheet came to an end in the neighborhood of Smuggler Mountain.

Description.—The porphyry is found freshest in exposures on the west side of the Castle Creek fault, at the southern margin of the Tourtelotte Park

area. Here, where shafts have gone deep enough to obtain portions of the rock removed from immediate surface alteration, the color is light gray, with a greenish tinge. Small phenocrysts of quartz and dark mica are rather sparingly disseminated, with bunches of pyrite, in a groundmass of fine and compact texture. Feldspar phenocrysts are very small and scarcely noticeable. Under the microscope the outlines of the quartz phenocrysts are somewhat rounded, and there are little bays which are occupied by the groundmass, showing corrosion by the magma previous to the consolidation of the groundmass. The mica is nearly colorless, with brilliant polarization colors; therefore it is probably muscovite, instead of biotite, as it seems in the hand specimen. Small, stout crystals of orthoclase are frequent, often showing Carlsbad twinning; these are often replaced, sometimes to a large extent, by crystalline calcite, which penetrates the feldspar along the edges and the cleavage cracks. This calcite is evidently an infiltration; it is coarsely crystalline and effervesces freely in the hand specimen. Pyrite occurs in small grains; almost invariably it is found embedded in calcite, when the latter is present, thus showing its secondary origin. Rarely there are small, slender crystals of plagioclase feldspar. The groundmass is finely microcrystalline, sometimes showing a tendency to micrographic structure. Zircon is found in small grains, as well as apatite; these are ordinarily inclusions in the mica.

In most of the district where active mining is carried on it is not possible to find any rock which is nearly so fresh as that described. The same tendency to alteration and change which has brought about the deposition of the ores is shown in the decomposition of the associated rock. On Aspen and Smuggler mountains and in Tourtelotte Park the porphyry is very light in color, with a gray or green tinge, which locally becomes brown from staining with iron oxide from the surface and along joints. It is porous and usually contains an abundance of pyrite. The circumstance that this pyrite is more abundant in the altered than in the fresh rock shows that its formation was comparatively late and probably a feature of the alteration itself. No mica phenocrysts remain in the altered rock, and the small altered phenocrysts of orthoclase, and rarely quartz, are barely distinguishable to the naked eye. Surface oxidation produces a phase speckled with brown, the spots being of iron oxide derived from the alteration of the sulphide; microscopic examination usually shows a kernel of residual pyrite in these

spots. Under the microscope the frequent small feldspar phenocrysts are seen to be sometimes kaolinized, but mostly altered to fibrous muscovite. The groundmass is holocrystalline, being made up of quartz and muscovite, which is derived from the alteration of the feldspars in the groundmass of the fresh rock. Calcite in small grains is common. Actinolite in sheaflike clusters and spherulitic forms is also found, clustered in certain areas and intergrown with quartz, which appears secondary.

Both megascopically and microscopically this rock is almost exactly like the White Porphyry at Leadville.

Source.—Besides the main sheet, which has been described, there were found in several places in the vicinity of Aspen cross-cutting dikes, vertical or nearly so, which may connect the bedded sheet with some concealed body of porphyry below. One of these localities is on Aspen Mountain, at the Bonnybel mine; the others are on Smuggler Mountain, at the Bushwhacker and Park-Regent mines and in the Smuggler. In both these places the dikes cut the Leadville dolomite, and they are undoubtedly continuous downward. It is also shown in the Bonnybel mine that a few small sheets were sent out from the dike, along the bedding, altering the dolomite to marble along their contact. In the dolomite these sheets are small and of limited extent, not extending outside of this mine; but on reaching the shales above the dolomite the dike merges into the main thick sheet. The actual junction of the dike with the sheet is not observable, having been removed by faulting.

Along the fissures represented by these dikes much molten material must have ascended. It has been shown by various geologists that the great sheets, and even the laccolithic bodies, of intrusive rocks, which are so common in the Rocky Mountain region, have ascended along narrow fissures; and the whole body of porphyry at Aspen may well have come up through a few such dikes as have been observed. It therefore seems probable that most of the porphyry which is found in the immediate vicinity of Aspen ascended along vertical or steeply inclined fissures from some point nearly or directly below. There was apparently little obstruction offered to the upward movement of the intrusive material until the horizon of the Weber shales was reached. At this point the resistance offered by the overlying rocks was so great that the accumulating material lifted the strata bodily, instead of forcing its way through, and spread out as a thick

sheet, becoming thinner in regions remote from the vent or vents. The corresponding White Porphyry of Leadville is also very largely developed as sheets at this same horizon the main sheet in Leadville overlying the Leadville limestone, as in Aspen. This general rock type is characteristic of the Mosquito Range, and is foreign to the Elk Mountain type, of which the diorite-porphyry is a representative. It is quite probable, therefore, that the White Porphyry of Leadville, and perhaps the other porphyries, ascended from the same source as the porphyry of Aspen; and when the intervening Sawatch Range is carefully mapped it is likely that dikes of porphyry will be found between the two districts. The intrusive rock, as already noted, would be represented in the granite or other very rigid rock only in the form of narrow dikes, although the amount of material forced up may have been as great as in the sedimentary rocks. These latter, on account of their plasticity, offer resistance to upward movement, and invite lateral movement along the channels naturally afforded by their stratification planes. Thus the intrusive rock accumulated in subterranean reservoirs, which deformation and erosion have now brought to the surface; but where the rocks have been planed down to the underlying granite only narrow and occasional dikes appear. The situation of Aspen is, therefore, intermediate between two great axes of eruptive activity, each of which has certain distinguishing features, one lying in the Elk Mountains and the other in the Mosquito Range or the Arkansas Valley; and the district evidently is, in spite of its geographical position, most closely associated with the latter axis.

Mr. Cross[1] has come to the conclusion that in the case of the huge laccolithic bodies of intrusive rock which are common in the Rocky Mountains, the narrow fissures along which the molten rock ascended, now occupied by dikes of the same material, must have ceased to exist as channels at the horizon of the laccolith, and suggests that the formation of such nonpersistent channels was due to some gradually exerted force, and not to any sudden violent rupture, such as might arise from earthquake action. A gradually exerted force would more easily be deflected by various causes, and the fissure might easily pass into some marked bedding plane. In the case at Aspen, however, any slight vertical fissure, however produced, would tend to disappear on reaching the shales. Through the

[1] Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1894, p. 240.

granite, quartzites, hard dolomites, and brittle limestones any movement would produce a well-marked shearing zone or set of closely grouped fractures; in the more plastic shales, however, any slight movement would be taken up by the uniform yielding of the entire mass, until the disturbance was adjusted, and the motion would thus entirely die out near the bottom of these plastic beds. Cases of the disappearance of faults in soft and shaly beds have been noted by the writer in this district, it having sometimes been possible to observe in a single exposure the whole process of diminution and disappearance without noticeable deflection.

AGE OF THE INTRUSIVE ROCKS.

The relative age of the diorite-porphyry and the quartz-porphyry in Aspen can not be stated, for they were not found in any place in juxtaposition. The diorite-porphyry sheet ranges in horizon from the top of the granite to the bottom of the Leadville dolomite; the quartz-porphyry sheet lies uniformly at the bottom of the Weber, and cross-cutting dikes are rare. Both these rocks have participated in all that the region has undergone in the way of folding and faulting. These disturbances began in late Cretaceous time, according to information furnished by neighboring districts, and Mr. Emmons[1] has assigned to this general period both the eruptive activity of the Elk Mountains and that of the Mosquito Range. The rocks are therefore in a general way contemporaneous, having been injected toward the beginning of the great mountain-making disturbance, and before the folding and faulting which followed. The movements in the rocks, however, must have begun very soon after these volcanic intrusions. It seems possible that the two processes may have begun simultaneously, and that the injection of the molten rock occupied only a comparatively brief period of time, while the strains which were generated at the same time found relief very slowly in the folding and faulting. In the Aspen district there is abundant evidence that the movement along most of the fault planes is still actively going on, and some important faults have originated in post-Glacial time.

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[1] Geologic Atlas U. S., folio 9, Anthracite-Crested Butte, Colorado; Geology of Leadville, p. 31.

CHAPTER II.

GENERAL DESCRIPTIVE GEOLOGY.

ASPEN SPECIAL MAP.

This map incloses an area which has been the most productive of the whole district. For this reason it has been made the subject of more detailed investigation than the other areas, and two special maps have been constructed on the 300-foot scale—one of Aspen Mountain and one of Smuggler Mountain (Sheets XXV and XXVII of the accompanying atlas). These detailed maps embrace the most complicated parts of the district, and it is in describing them that most of the structure will be brought out.

Through the whole central part of the area, running from southeast to northwest, lies the broad, drift-filled valley of the Roaring Fork. This offers a barrier to close investigation, since the valley drift is so thick that the underlying bed rock is nowhere shown. Judging from the attitude and position of the strata on the north and south sides of the valley, however, there is no great complication beneath the valley itself, and the actual structure may be inferred with comparative accuracy. It is probable that the drift is not of exceedingly great depth, and that the actual bed-rock valley bottom is a shallow, basin-shaped depression, having a broad, curved surface, resulting from glacial erosion. This opinion is based on an examination of mine workings which run underneath the valley. Parts of these workings have traversed nearly the whole of the distance between Smuggler and Aspen mountains, and the comparatively slight depth at which they lie shows that there can not be any canyon-shaped indentation in the bed rock. The present outline of the valley, therefore, has been determined by glacial erosion.

The whole northern part of the area mapped is made up of red Maroon sandstones, which have a uniform westerly dip, forming a simple monocline, and which therefore offer no structural difficulties to the investi-

gator. Through the western part of the area there runs in a nearly north-south line the great Castle Creek fault, which brings the Triassic beds on the west against the Maroon on the east, on the extremity of West Aspen Mountain; and farther south, as the throw of the fault increases, the Archean granite comes finally to lie against the Triassic. The narrow strip which lies between the Castle Creek fault and the west side of the area mapped consists chiefly of red beds of the Maroon and Triassic. The latter predominates, but in Keno Gulch is the contact of Maroon and Triassic, which here, as elsewhere, is marked by a change from thin-bedded, shaly, and calcareous brown sandstones to the bright-colored, more massive, and purer Triassic sandstones. Throughout the whole of this strip the beds are overturned, so that the Maroon beds overlie the Triassic at their point of contact. All of these overturned beds form part of the closely compressed, easterly dipping, and northerly pitching syncline, which lies immediately west of the Castle Creek fault.

Plate I (opposite p. 1) gives a general view of the area shown on the Aspen special map. The view is taken from a point down the Roaring Fork Valley at some little distance beyond the western edge of the map. In the foreground of this picture is the broad, flat, sage-covered valley bottom, made up of morainal material, which has been worked over by water action. Through this plain the Roaring Fork and its tributary streams flow, having carved out gorges of comparatively slight depth in the drift. At the right of the picture is Aspen Mountain, with its two prominent ridges separated by the broad, northerly facing depression. The nearest of these ridges is West Aspen Mountain; the farthest is East Aspen Mountain. The flat depression between the two occupies practically the same area as does an underlying synclinal fold in the rocks. The productive portion of Aspen Mountain lies almost wholly in this broad depression, although recently considerable ore has been discovered on the very point of West Aspen Mountain. In the central part of the picture the hills on both sides of Roaring Fork Valley appear to come together, and there is actually a great narrowing in the valley, caused by change of formation. West of this narrow point there lie sedimentary rocks, which, as in the case of the Weber and the Maroon formations, are often soft, and here a broader valley has been eroded; at the point of narrowing, however, granite comes in on both sides. It is probable that the broad valley below this granite gateway was

the bed of a lake subsequent to the greatest activity of the Glacial period, and that on the bottom of the lake the morainal material was sorted and leveled so as to form the flat plain which exists at present. In the background, looking up Roaring Fork Valley, are seen the peaks of the Sawatch. On the left hand, or northerly side of the picture, most of the hillside is granite, with the sedimentary formations of Smuggler Mountain coming in above; these sedimentary formations are continuous with those in the hollow of Aspen Mountain. In the extreme left is the east side of Red Mountain, which is separated from Smuggler by the valley of Hunter Creek. The name Smuggler Mountain is applied especially to the small, flat-topped hill with heavy side gulches which lies to the west and below the mountain, whose outline stands out against the sky. The top of this hill is not far above the level of Hunter Creek Valley, and is heavily covered with glacial drift. The main mountain back of Smuggler Mountain proper is of granite, and this rock extends from here to the gateway in the Roaring Fork Valley. In the left foreground, on the spur of Red Mountain, come in the red Maroon beds.

ASPEN MOUNTAIN.

FOLDING.

In the northeast part of the area shown on the Aspen special map (Atlas Sheet IX) the only feature in the plication of the beds is the usual simple westerly dip, which extends from the granite through the Cambrian, Silurian, Devonian and various Carboniferous formations. In the extreme northwestern corner of the area the steep westerly dip grows shallower, showing the approaching synclinal structure which is exhibited near Red Butte, where the beds abut against the Castle Creek fault.

In the area shown on the southern part of the map, however, on Aspen Mountain, there is a sudden and remarkable change in the position of the beds. Here is developed a new folding in two directions, one parallel to the strike and another one at right angles to it. The longitudinal section (see Section G, Aspen district map, Atlas Sheet VII) shows a sudden bending-up of the beds along the strike at this point. This doming-up, as measured in the section referred to, amounts to 5,000 feet or more in the distance between the Roaring Fork and the top of Aspen Mountain. This amount is partly due to intervening faults, which likewise tend to raise the beds toward the south. These faults, however, are intimately connected

with the doming-up, and probably both have originated in a single cause; so that in a general way the amount of uplift as measured is correct.

The uplifting of the beds along the strike seems to have reached its maximum in the north half of the area shown on the Tourtelotte Park special map, but its effects are seen to less extent farther south. All the rocks between the Roaring Fork and the southern end of the district show this remarkable uplifting, accompanied by minor folding and by intense faulting; so that the district is entirely different from that adjoining it along the strike to the north. On account of its peculiar deformation this region becomes isolated and conspicuous, and its difference from the adjoining areas becomes even more important when it is considered that the center of greatest uplift and disturbance has also been the chief center of ore deposition.

Parallel with the main axis of this domelike uplift, which is also parallel with the general strike of the beds and with the Castle Creek fault, are the axes of minor folds which corrugate the dome. The chief of these minor folds is a syncline lying on the eastern side of the uplifted area. This syncline, which has been much broken by later faults, many of which are important, is most strongly developed just south of Aspen, where it occurs in the depression between West Aspen and East Aspen mountains. It has a general pitch to the north, so that the beds in its center strike east and west, while those on its western side have a northwest strike, and on its eastern side there is a southwest strike, which approaches and merges into the normal strike of the beds throughout the whole district. This syncline is continuous up into Tourtelotte Park, but grows constantly shallower toward the south, and finally dies out; so that in the southern half of the area shown on the Tourtelotte Park special map it can not be distinguished. North of Aspen Mountain it also becomes greatly diminished in importance, but it can be traced along the eastern side of the Castle Creek fault for a considerable distance. In the beds on Red Mountain, a short distance northeast of Red Butte, there is an easterly dip which proves the synclinal structure. This structure, as well as that of the overturned beds to the west of the Castle Creek fault, is shown on Section C of the Aspen district map (Pl. VII).

East of this deep, broken syncline on Aspen Mountain the dip of the beds flattens, so that on the ridge of East Aspen Mountain an approaching

anticlinal structure is indicated; but erosion on this mountain has removed all traces of the eastern part of this anticline. Farther south along this same axis of folding, however, a distinct anticline is traceable through a large part of the area shown on the Tourtelotte Park special map (Atlas Sheet XII), and in this area there is even another flattening of the beds to the east of the anticline, which indicates the existence of a slight final syncline resting immediately against the granite.

The deformation due to folding in the southern part of the area shown on the Aspen special map may therefore be summed up as a local uplift, which had its maximum movement in Tourtelotte Park and died away from this point very rapidly toward the north, so that its effects are not at all seen on the opposite side of the Roaring Fork Valley, while on the south it also dies away, but much more slowly. This uplifting was accompanied by minor corrugations or foldings, whose axes are roughly parallel to the main axis of the uplift and to the Castle Creek fault.

Most of the upward movement has actually taken place along fault planes, but these faults are confined to the disturbed areas and die out toward the north. The main series runs north and south, parallel with the minor foldings and with the axis of main uplift. It appears from this parallelism between the faulting and the uplifting that the uplifting itself was not due, primarily, to faulting, since the blocks of strata included between these north-south faults have actually undergone much bending previous to breaking, but that the uplifting and the faulting are both the results of a single disturbing influence, and that the faulting probably took place mainly after the initiation of the upthrust movement. The upward tension evidently found relief more easily in motion along certain north-south vertical planes of fracture which had been developed at the same time as the Castle Creek fault, than in the actual bending of the rocks; thus it happens that the main uplifting has taken place along these parallel faults.

FAULTING.

Castle Creek fault.—The Castle Creek fault outcrops in the southwestern corner of the district mapped, in Keno Gulch, where it is exposed in several short tunnels which run from the intercalated sandstones and shales of the upper Maroon formation eastward into the granite on the other

side of the fault. In these tunnels the fault seems to be dipping to the east, as well as can be judged from the limited exposures. A little distance westward down the gulch from the outcrop of the fault there come in the bright-red, more massive sandstones, which probably form the lower part of the Triassic beds. From this point northward along the west side of the fault the northerly pitch of the Triassic beds brings in successively higher and higher strata. In this way nearly the whole Triassic comes to the surface along the narrow strip shown on the Aspen special map, for the Maroon formation is found in the southwestern corner, and a short distance beyond the limits of the map, at Red Butte, the Gunnison formation comes in.

Where the Castle Creek fault outcrops in Keno Gulch it has nearly its maximum displacement, which is indicated, as shown by sections of the Aspen district map, by an upthrow on the east side of about 9,000 feet. From this point the fault is traceable northward to the northern end of Aspen Mountain, where it passes under the drift of the Roaring Fork Valley, and does not outcrop until it reaches Red Butte, on the opposite side of the valley. Near the northern extremity of West Aspen Mountain the fault is cut by a tunnel which runs from near the bed of Castle Creek eastward through the Triassic sandstones into black Weber shales. The amount of displacement indicated by the passage from the Triassic into the Weber is very much less than that shown by the contact of upper Maroon and granite in Keno Gulch, although the distance between the two points is very slight. This great diminution in throw is explained by the presence of a cross fault with a northeast trend, which has been discovered running diagonally across the northern end of West Aspen Mountain at this point. This fault is called the Mary B., and although short, has a heavy throw, bringing the lower Maroon and upper Weber formations against the Silurian, Cambrian, and Archean rocks, which southward from here lie on the east side of the Castle Creek fault. The throw of the Castle Creek fault, as measured at Red Butte, which is not far from the northern termination of the fault on the Aspen special map, is only about 2,600 feet, a great decrease from the 9,000 feet at the southern end of the map. This decrease in throw is partly owing to the difference in the dip of the beds on the east side and on the west side of the fault; for while both have a northerly pitch, those on the east side are, on West Aspen Mountain,

considerably steeper. Most of the decrease, however, is due to the cross faulting which has been noted. West Aspen Mountain is really an isolated block, included between the Pride fault, Castle Creek fault, and Mary B. fault. The northern end of West Aspen Mountain is also the northern end of this upthrust block, which comes to an end suddenly at the meeting of the Mary B. and the Pride faults. The whole of this block is enormously elevated above the surrounding formations, but the elevation is much greater at the southern end than at the northern, which is due to the steep northern pitch of the beds on the northern point of West Aspen Mountain. In this latter locality dragging of the beds has produced a series of east-west faults, which run across from the Pride fault to the Mary B. or the Castle Creek fault.

Pride fault.—This fault receives its name from its occurrence in the Pride of Aspen mine, the most northern point at which it has been located. Here the fault has a downthrow to the east of about 2,000 feet, thus bringing down on the east side the basal micaceous limestone of the Maroon, while on the west side is the Silurian dolomite. From this point the fault runs straight south through the Igneous tunnel, then through the Sixty-six shaft and just west of the Broadway tunnel, and so to the very summit of the hill, where it passes into granite on both sides and can not be traced farther. In the Igneous tunnel the fault brings the Weber shale on the east against the granite on the west. Near the Broadway tunnel there is blue limestone belonging to the Leadville formation on the east side of the fault, with granite on the west side. A short distance north of the Broadway the main Pride fault splits into two. The course of the more westerly of these two is nearly continuous with that of the main fault previous to dividing. This branch may, therefore, be still called the Pride fault, while the eastern branch, which deviates from the main fault a little in trend at the point of parting, but immediately swings round and runs parallel with it out of the area mapped and for a long distance across the Tourtelotte Park area, may be called the Saddle Rock fault, from its passing close by the Saddle Rock shaft in Tourtelotte Park. The effect of this division is to apportion the displacement of the single fault between the two derived faults. In Section A, where there is only a single fault, its throw is shown to be about 2,000 feet. In Section B, however, it is considerably less, while the Saddle Rock fault, which here comes in to the east of the Pride fault proper, has a throw of

1,000 feet or more. The combined throw of these two faults is probably not far distant from the entire throw of the Pride fault north of the point of junction.

Going south from the northern extremity of West Aspen Mountain, where the Pride fault is first located in the Pride of Aspen mine, one passes successively to lower and lower formations, since the dip of the beds is steeply to the north. The Silurian dolomite, which is found on the west side of the fault in the Pride of Aspen mine, continues for some little distance to the south, the outcrop being made broader by the general parallelism between the bedding and the slope of the surface, and also by the general downfaulting of the end of the mountain to the south in parallel blocks. In one of these blocks, however, the position of the beds is so altered that the dolomite and limestone of the Leadville formation outcrop on the east side of the hill and lie against the Pride fault. This block is sandwiched between two others where only Silurian strata outcrop. (See Section B, Aspen special map, Atlas Sheet X.) Going still farther south, one crosses over the steeply dipping Cambrian beds, with a thin included sheet of diorite-porphyry at the bottom, and so on to the basal granite. This granite continues outcropping on the west side of the fault quite to the southern limit of the mapped area.

On the east side of the fault there exists, in the Pride of Aspen mine and neighboring localities, the basal member of the Maroon formation, which is immediately overlain by the Weber formation a little to the south. From this place to the point where the Saddle Rock fault splits off from the Pride fault there is continuous shale in outcrop on the east side. The point of division is in the vicinity of the Pioneer tunnel. Farther south one comes successively upon lower and lower formations in the block between the two faults; thus the Parting Quartzite and the Silurian dolomite are successively passed over, and at the very summit of the hill the Cambrian quartzite outcrops and has been cut by tunnels. Just south of this there comes in granite underlying the quartzite; there is here, therefore, granite on both sides of the Pride fault, and its course can not be followed farther, nor can the amount of its displacement be known. It is represented on the Tourtelotte Park special map (Atlas Sheet XII) as running a short distance farther south, and then as dying out or stopping in the vicinity of an east-west fracture; this, however, is purely arbitrary. It is

a fact which has been noticed in the parallel faults which belong to the same system as the Pride that the throw diminishes toward the south, and that there is, consequently, a gradual dying out; but this disappearance of fault movement is not so rapid in these cases as is shown for the Pride, so that it is probable that this fault continues much farther into the granite toward the south. Its dip is nearly vertical, but it often, and perhaps usually, has a steep easterly dip, as shown in the cross sections.

Along the Pride fault there has been extensive mineralization, which is shown in many places. The ore in the Pride of Aspen mine is found near this fault, as well as that in other workings. There is even a marked mineralization at the contact of quartzite on the east side of the fault with granite on the west side, at the very top of the hill, before the fault passes finally into the granite. This mineralization is shown in tunnels, where the quartzite is much altered and impregnated with iron and copper. Although the ore at this point has not proved to be of any great value, it is interesting as showing that the fault itself has been the chief channel for the ore solutions, and one of the chief things in determining the final location of the ore.

Saddle Rock fault.—This fault, like the Pride, is well located and defined along most of its course by explorations which have been made in the search for ore. Its point of junction with the Pride fault is probably a short distance north of the breast of the Pioneer tunnel. This tunnel runs across the fault from shale into blue Leadville limestone. Opposite and just west of this locality the Pride fault is shown cropping between the Broadway tunnel and the Sixty-six shaft. The belt between these faults at this point is very narrow, being but 150 or 200 feet, showing a marked convergence of the two toward the north; they probably unite not far north of this point, for only one fault is indicated by the Igneous tunnel. Just south of the point where the Saddle Rock fault is cut by the Pioneer tunnel the fault describes a curve toward the east for a distance of 300 or 400 feet. This curving is sufficiently well indicated by various tunnels and outcrops along the line on which it is drawn on the map. From this extreme easterly point of outcrop the line of faulting on the surface swings back a little to the west, and then continues nearly parallel with the main Pride fault, but apparently slightly approaching it. This curving of the fault outcrop is probably due to a local flattening, so that its dip here must be compara-

tively slight. Where the fault becomes again straight and its outcrop parallel with that of other faults of the same system, its plane has probably again become vertical, or is perhaps very steeply inclined toward the east.

Cutting across this curved line of fault outcrop, like the string of a bow, is a slight fault which is in more direct continuation with the main Saddle Rock fault than is the fault with the curved outline. The main displacement, however, has taken place along the most easterly plane, and the movement along this straighter fault is very slight, being a downthrow on the east side.

The Saddle Rock fault is well shown in the Great Western, New York, and Monarch tunnels; also, nearer the surface, in the Late Acquisition incline and the Iron tunnel. From here it runs into the area of the Tourtelotte Park special map (Atlas Sheet XII), where it may be traced to the south for a long distance. Its displacement on Aspen Mountain is seen, in Section C, to entail as much as 1,000 or 1,200 feet downthrow to the east. Toward the south the throw diminishes rapidly. This is due to the fact that the beds on the west side of the fault have a flatter northerly pitch than those on the east side, so that the formations on opposite sides of the fault tend to converge This convergence ends in the final dying out of the fault.

Along its whole course this fault is more or less mineralized, and the nature of the ore shows that it was formed in place; there is some evidence, however, of slight movement which has taken place subsequent to the ore deposition. This fault, then, like the Pride, must be considered as having developed almost entirely previous to the period when the ore-bearing solutions circulated through the rocks.

Sarah Jane fault.—The next important fault on Aspen Mountain to the east of the Saddle Rock fault is one which belongs to the same system, having a nearly vertical dip and a north-south trend corresponding with that of the faults which have already been described The outcrop of this fault is to a great extent concealed by a covering of talus or slide material and glacial drift; but in a general way the line of faulting is well marked, running down the middle of the drift-filled basin which lies between the prominent ridges of East Aspen and West Aspen mountains, very nearly as drawn on the map. Its presence is indicated by the fact that the upper contact of porphyry and Weber shales lies at a considerable distance farther north on the west side of the fault than it does on the east. The syncline of Aspen

Mountain has a northerly pitch, steeper than the slope of the mountain; so that successively higher and higher beds outcrop toward the north along each of these faulted blocks. The shifting in position of the upper contact of porphyry and shale is shown by the fact that the Great Western and New York tunnels run in porphyry on the west side of the fault, while on the east side there are only Weber shale and limestone developed by the explorations; and on the latter side the porphyry is found only near the top of the hill.

The displacement of the Sarah Jane fault is chiefly a downthrow on the east side, never very great. In the northernmost of the 300-foot sections on the Aspen Mountain map it is shown to be about 300 feet. (Section A, Atlas Sheet XXVI.) In Section B it is drawn as having about 200 feet downthrow, and in Section C, which is the southernmost, about 350 feet downthrow. These measurements are, however, based on very few data, and are, therefore, not necessarily accurate; doubtless the actual throw of the fault may be more uniform than has been represented.

To the south the Sarah Jane runs into Tourtelotte Park, where there are many outcrops and mine workings which afford abundant opportunity to trace its course. These explorations show that while the throw is always downward to the east, yet it continues to decrease slightly toward the south; so that in the middle of the area shown on the Tourtelotte Park special map it dies out and is not farther traceable. This fault has not been prospected to any extent on Aspen Mountain, but in Tourtelotte Park it shows evidence of belonging to the same general class as the Saddle Rock, Pride, and Castle Creek faults, since it is mineralized to a greater or less extent along its whole course, and since there is no evidence of any great movement subsequent to the ore deposition.

Schiller fault.—The Schiller fault may be traced on the surface, but is best shown underground, in the Durant, Schiller, and Aspen mines. This fault has a north-south trend and is nearly vertical. It belongs to the same general system as the faults which have already been described, but it has a greater difference of throw at different places than the others, as shown in sections taken at various points. In the southern part of the Durant mine, which is almost exactly below the southern edge of the district mapped, at the point where the outcrop of the Schiller fault passes into the area of the Tourtelotte Park special map, the fault seems to have very

little throw, although there is a marked zone of fracture. From this null point southward the throw is very slight and has no constant direction. The tendency appears to be toward a slight downthrow to the east, as seen in the extreme southern part of the Durant mine, and as represented on Section G of the Tourtelotte Park mining map (Atlas Sheet XXIV). It is probable that this fault dies out entirely a short distance south of the null point mentioned, and is not found except in the extreme northern end of the area of the Tourtelotte Park special map (Atlas Sheet XII). That part of the fault, however, which lies north of this null point has a steadily increasing downthrow on the west side. In Section C of the Aspen Mountain map (Atlas Sheet XXVI) this downthrow is shown to be only about 50 or 60 feet, while in Sections B and A, which are based on rough estimates, it is represented as about 400 feet. This increase in throw is due to the fact that the rocks on opposite sides of the fault differ in dip. those on the west side having a steeper northerly dip than those on the east, so that the formations tend to converge toward the south.

Parallel with the main Schiller fault are several smaller breaks, which evidently belong to the same system, and which vary in throw in the same general way as does the main fault. These are distinguished in mine workings, where there are also numerous slight cross faults and fractures, but they can not be described in detail here.

In mine workings it is found that ore occurs along the Schiller fault, apparently in place; so that this fault, like the others, originated previous to the period of ore deposition.

Aspen fault.—The Aspen fault is a slight break, but is important on account of the peculiar position which it occupies. At the junction between the areas of the Aspen and the Tourtelotte Park special maps the uplifting on Aspen Mountain reaches its maximum, and the beds begin to assume the flatter position and less folded structure characteristic of Tourtelotte Park; and the line which separates the two maps also separates two districts which differ materially. South of this line, in Tourtelotte Park, the Aspen Mountain syncline becomes continually shallower and finally dies out. Just to the north of it, however, the syncline is more pronounced than at any other point. Here the rocks have been so greatly folded that the eastern limb of the syncline becomes nearly vertical, and is locally, as shown in the Durant and Aspen mines, slightly overturned, so that the beds dip steeply to the

east. A short distance below this point of overturning the beds resume their normal succession very suddenly, and the steep easterly dip changes to a comparatively flat westerly one. The beds having this flatter dip form the eastern part of the bottom of the syncline.

At the point where the steep dip of the overturned beds changes to the normal westerly dip there is a slight fault, as if the change in position had been too abrupt for flexure without breaking. This breaking is not marked by any single plane, but by several parallel ones; the chief plane of movement has been called the Aspen fault. On the east side of this fault the beds are vertical or have a very steep dip, which may be either normal or reversed, while to the west of the fault the beds have a comparatively flat dip, and appear in east-west sections as nearly horizontal. The dip of the fault, as shown in the sections, is, as a rule, nearly vertical, becoming in depth often a little easterly, and on approaching the surface flattening out and acquiring a dip to the west, which upward grows progressively less. Where, therefore, the Aspen fault is encountered in the lower workings of the mines, it is, with reference to the beds lying east of it, which are vertical or nearly so, somewhat in the nature of a bedding fault, while it cuts across the flat-lying beds on its west side at nearly right angles. Higher up in these mines and near the surface, however, the beds on opposite sides of the fault become more nearly alike in their attitude, both acquiring a decided but generally not an extreme westerly dip. In passing upward into these rocks the Aspen fault seems also to change and to approach more and more nearly coincidence with the bedding. In this way much of its throw, which, even in the deepest parts of the mine, is not found to be very great, is lost, the movement being taken up along the bedding planes of the strata. It therefore becomes progressively more difficult to trace, and it very likely passes into the Silver fault, as is represented in the 300-foot sections on the Aspen Mountain map. The actual nature of this curving fault is hard to summarize; it has in general a slight downthrow to the east, which is very small, but increases with the difference in dip of the beds on its two sides. The greatest actual throw, as measured between two stratigraphical planes on opposite sides of the fault, is probably not more than 150 feet, and the amount of this throw decreases toward the surface, and also in depth, for in depth the rocks again tend to assume more uniform dips on both sides of the fault.

Since the dip of this fault is mainly toward the west, this movement is indicative of a reversed or thrust fault; and in a general way this seems to be its nature, although, as already stated, in the lower part of this fault, as exposed in mine workings, the downthrow on the east side is the direction of the dip, and so constitutes a normal fault.

The Aspen fault is probably restricted in extent, both to the north and to the south. Its maximum development probably coincides with the maximum amount of folding in the Aspen Mountain syncline, and this maximum folding apparently occurs in the southern part of that portion of Aspen Mountain which is shown on the Aspen special map. This fault can not be traced any distance southward in the area of the Tourtelotte Park special map. In Section A of the Tourtelotte Park mining map (Atlas Sheet XXII) it is represented as being present, but with a very slight throw; and it seems quite certain that it does not exist far south of the plane of this section. On the northern end of Aspen Mountain there also appears to be a marked diminution in the intensity of the folding and in the amount of displacement by the Aspen fault. Section C of the Aspen Mountain map (Atlas Sheet XXVI) probably traverses the point near which this fault has its greatest development. In Sections A and B of the same map it is represented as being present but having much less importance. It probably dies out to the north under the Roaring Fork Valley, and is therefore more restricted than any of the other north-south faults which have been described, being present only on Aspen Mountain.

In the process of mining large and valuable bodies of ore have been discovered along this fault, so that it belongs to the same general class as the faults which have already been mentioned, namely, the premineral faults.

Bonnybel and Chloride faults.—These faults are shown on the map as having only a limited extent. They are approximately parallel, having a general northwest trend and a southwest dip. They are well shown in the Bonnybel and Durant mines, where their existence and the amount of dislocation have been well determined in the course of extensive lawsuits. Like many other faults, these are not simple; but, strictly considered, the disturbance has consisted in the breaking up into thin slices of a wedge of rock, which has a northwest trend and a southwest dip. Within this wedge there are many faults parallel to its sides, all of which have some throw. For purposes of discussion, however, the displacement may be

considered as taking place along the two planes which form the opposite boundaries of the wedge, and to these planes the names Bonnybel and Chloride faults have been given. These two faults may be described as slightly converging both to the northwest in their trend and downward in their dip, hence they may soon come together in either direction and form a single plane, or, more properly speaking, a narrow zone of fracture, which finally runs into the Silver fault and there terminates, so far as can be traced. The general movement of these two faults is to thrust down the block between them relatively to the surrounding beds. This movement is best seen by the position of the Parting Quartzite, which between the faults outcrops farther down the hill than it does on either side of this downfaulted block. The maximum amount of this throw may be put at about 150 feet.

These faults, and indeed the whole of the highly fractured wedge between them, have been intensely mineralized, and therefore the movement was premineral. The faults are not traced very far to the southeast from the point where they leave the area of the Aspen special map. The Bonnybel fault is represented on the Tourtelotte Park special map (Atlas Sheet XII) as terminating at a minor intersecting fault, while the Chloride fault is represented as running into the Justice near the point where that fault unites with the Copper fault. Both the Justice and the Copper faults, however, have a somewhat different trend, which is north, instead of northwest, and both of these faults belong to a distinct system from those which have been described on Aspen Mountain. This system is characterized by having its greatest development in Tourtelotte Park, while the Aspen Mountain system has its greatest development on Aspen Mountain, and by the fact that the greatest displacement took place subsequent to the period of ore deposition, while in those of the Aspen system it took place previous to this period.

The Chloride and Bonnybel faults are therefore quite distinct in point of age from the Justice and Copper faults, and if the Chloride fault actually runs into the Justice, as it seems to do, they still must be considered as belonging to separate systems. It is probable, however, that the original fracture, which was formed at a very early date, was actually continuous along the planes now occupied by the Chloride and Justice faults, and that in the case of the Chloride fault the maximum displace-

ment took place at an early period before the ore deposition, while the rest of the fracture was undisturbed, and that the later movement, which was centralized in Tourtelotte Park, produced the Justice fault along the southern part of this fracture in postmineral times.

East Aspen Mountain faults.—On the east side of East Aspen Mountain there comes in a series of nearly parallel faults, which extend continuously into the Tourtelotte Park district, where they are much more important than on Aspen Mountain, since they belong to the Tourtelotte Park system, which has its greatest development at a point farther south than the Aspen Mountain system, to which most of the faults on Aspen Mountain belong. These faults, as shown on East Aspen Mountain, have a general northwest trend, which is a slight variation from the normal north-south trend of the same faults, or of faults belonging to the same system, in the Tourtelotte Park district. With the change in trend on Aspen Mountain there is also a convergence, so that the various faults tend to unite, and after uniting, to die away. The amount of dislocation decreases steadily from the south toward the north, and on the north side of East Aspen Mountain, as is shown by the displacement of the Parting Quartzite, which is found to be nearly continuous in outcrop, the system comprises only two planes of slight faulting. Judging from these indications, it is likely that these faults die out very soon after leaving East Aspen Mountain, and it is probable that, like the Chloride and Bonnybel faults, they stop on reaching the Silver fault. No ore has been found along them on East Aspen Mountain, and in the Tourtelotte Park district it has been shown that they were developed subsequent to the period when the ores were deposited, and are, therefore, not at all mineralized.

At the extreme southern end of the map, on East Aspen Mountain, there is shown one of the cross faults that are so common in the Tourtelotte Park district, which belongs to the general system of east-west postmineral faults that is there so conspicuously developed. In this case the fault has apparently brought the Silurian dolomite on the south side into contact with the Archean granite on the north side.

Mary B. fault.—The Mary B. fault is so named from its being cut in the Mary B. workings, which pass through the lower arenaceous limestone of the Maroon formation into the dolomite of the Silurian. In a tunnel which starts from near the bed of Castle Creek in Triassic sandstones and runs

east across the Castle Creek fault, black Weber shales are found on the east side of the fault. It seems very probable that in this case the shales lie on the northwest side of the Mary B. fault, as represented on the map, and that the contact of basal Maroon limestone and of Weber rocks lies between the two tunnels mentioned. The displacement of the fault is indicated by the change from the base of the Maroon to the Silurian, which shows a downthrow on the northwest side of about 2,000 feet. The fault probably splits off from the Castle Creek fault near the northern end of West Aspen Mountain, and, assuming a northeasterly trend, and thus diverging from the Castle Creek fault, which has a northwesterly trend, it soon runs into the Pride fault.

At the extreme northern point of West Aspen Mountain the throw of the Pride fault is almost identical in direction and amount with that of the Mary B. fault, so that the contact of Maroon and Weber is seen on the opposite sides of the mountain, separated only by the wedge-shaped upthrust block of Silurian, Cambrian, and Archean. Where these two faults come together, therefore, as they evidently do at the very end of the mountain, the effect must be to neutralize each other, so that while the Pride fault may be continuous farther northwest into the Castle Creek fault, its throw has become very slight. Along the Mary B. fault there has been discovered in the Mary B. tunnel a body of ore, in part at least high grade, which has evidently been formed in place; therefore this fault is, so far as can be ascertained, identical in age with the faults already described, being antecedent to the ore deposition.

Cross faults.—On the map near the northern end of West Aspen Mountain are shown three parallel east-west faults, which have a northerly dip somewhat steeper than the slope of the mountain. (See Section B, Aspen special map; Atlas Sheet X.) These faults divide the point of the ridge into parallel slices, which have moved one upon the other. The general movement appears to be a downthrow to the south, and since the faults have a northerly dip, they come under the head of reversed faults. This movement is indicated by the outcropping blocks of quartzite on the west side of the mountain. In one of the blocks, however, there outcrops, as shown on the map, a narrow belt of Parting Quartzite. The rocks in this block seem to differ from those in the adjoining blocks, in that there has been a change in the position of the beds, giving a more easterly dip. In this way the Parting

WEST ASPEN MOUNTAIN.

Quartzite is exposed on the top of the hill, and as the rocks dip more steeply on the east side of the hill than does the slope of the hill itself, there are found below the Parting Quartzite outcrop the dolomite and blue limestone of the Leadville formation On both sides of these Leadville rocks, and separated from them by the cross faults, is the Silurian dolomite. At this point the block presents in cross sections the aspect of being downfaulted relatively to the blocks on both sides, as is shown in Section B, although on the west side of the hill, as shown by the outcropping Cambrian quartzite, the block has the same general movement as its neighbors, being downthrust from the block next north, and upthrust relatively to the block next south.

In one of the parallel east-west faults of West Aspen Mountain, which is cut by the Falco tunnel, some ore is found. These minor faults, therefore, are also probably older than the ore deposition.

Pl. II is a view of the end of West Aspen Mountain, taken from the valley near the Roaring Fork and looking southwesterly up Maroon Creek. The outcropping rocks, as best seen in the case of the Silurian dolomite on the extreme north face of the mountain, have the same angle of dip as does the mountain itself, while the somewhat steeper faults run up the mountain in the shallow gulches or depressions lying between the outcropping, nearly parallel ridges, which are seen in the picture. In the foreground of this plate is the Roaring Fork, while in the distance, on the west side of Maroon Creek, are seen the upper Triassic beds and the rocks of the Gunnison formation, with the Dakota sandstones forming the top of the ridge as it slopes away gently to the west.

Silver fault.—The Silver fault is developed continuously by mine workings through the whole of its course across the area of the Aspen special map. It is marked by a thin zone of brecciated material, whose composition often shows that some of it has been dragged from a distance, and by polished and striated walls of hard rock. On Aspen Mountain there lies always to the east of the fault the blue Leadville limestone, and to the west the main thick sheet of porphyry. Between the porphyry itself and the fault there is usually a zone of crushed and broken shale, often mixed with porphyry, which is never very thick and sometimes is almost entirely absent. On Aspen Mountain the Silver fault is not exactly parallel with the bedding, for in the northern part of the mountain it cuts deeper into the beds, so

that the blue limestone becomes continually thinner. Under the Roaring Fork Valley the Silver fault cuts out the blue limestone altogether, as may be observed in the Mollie Gibson workings; and from this point north through Smuggler Mountain to the edge of the area mapped the Leadville dolomite lies on the east side of the fault.

Extending a short distance into Smuggler Mountain, north of the point where the blue limestone is cut out, is a narrow band of porphyry lying next the fault on the west side, but this, too, is only a wedge left by the encroaching fault, and dies out completely in Smuggler Mountain, so that it is not found at all in the northern part. Throughout the northern part of the area shown on the Aspen special map (Atlas Sheet IX), therefore, the amount of displacement appears to have been greater than in the southern, for in the southern part it has removed only a part of the Weber shale, which lies underneath the main sheet of porphyry, while in the northern part it has removed the whole of this shale, together with the porphyry sheet and the blue Leadville limestone, with part of the Leadville dolomite. Just beyond the northern limits of the Aspen special map the fault cuts still farther down, so as to remove the whole of the Leadville dolomite, the Parting Quartzite, and a part of the Silurian.

The Silver fault everywhere shows evidence of great mineralization, and along it most of the ore thus far taken out has been discovered. It therefore belongs to the premineral set. All the other faults of Aspen Mountain, however, displace the Silver fault, when they cut it, in exactly the same proportion as they do the rock formations, so that they must have been developed at a distinctly later time than the Silver fault.

RÉSUMÉ OF STRUCTURE ON ASPEN MOUNTAIN.

In the eastern part of the area the beds have the nearly uniform westerly dip which is persistent throughout a large part of this belt of ore-bearing rocks, while in its southwest part the rocks are uplifted toward the south so as to form a sort of dome, whose northern termination pitches steeply toward Roaring Fork Valley. The north face of this dome, as seen on Aspen Mountain, is bent into minor folds parallel with the longest axis of uplift, of which the chief is a shallow northerly pitching syncline, which occupies the space between East Aspen and West Aspen mountains. East of this syncline the beds flatten somewhat and tend to assume an

anticlinal structure; but if this anticline was ever developed in the area shown on the Aspen special map, it has been removed by the erosion on East Aspen Mountain.

The faulting has occurred almost entirely subsequent to the folding, and is conspicuously best developed in the region where this folding had been greatest, namely, on Aspen Mountain. The Silver fault, which runs through the whole mineral-bearing district from northeast to southwest, was probably developed at about the time of the folding. The other faults of Aspen Mountain are more limited in extent, although they are very important. Chief among them are certain nearly vertical north-south faults, which are parallel to the Castle Creek fault and have an intimate connection with it.

The Castle Creek fault has its maximum development near the southwest corner of the area, in Keno Gulch, its throw being greater there than anywhere else in the district. From this point it diminishes both to the north and to the south. The heaviest of the north-south faults of Aspen Mountain lie nearest to the Castle Creek fault, and as the distance from the Castle Creek increases the throw of the parallel faults becomes generally less and the persistence north and south diminishes. These Aspen Mountain faults are apparently of the same age as the Castle Creek fault, all having the same trend and all having been formed previous to the ore deposition; and, like the Castle Creek fault, they have their maximum development on Aspen Mountain. The Castle Creek, the Pride, the Sarah Jane, and the Saddle Rock are continuously traced into the Tourtelotte Park district, all of them growing less toward the south and the smaller ones completely dying out. In the Schiller fault the diminution toward the south is much more rapid, for here the null point is reached at the southern end of the Aspen area, and the fault has not been traced into Tourtelotte Park. The Aspen fault, which is the slightest and the most easterly of the series, apparently dies out more suddenly in both directions, since it has not been traced into Tourtelotte Park and does not appear to be important in the north end of Aspen Mountain. All these faults disappear under the drift of the Roaring Fork Valley to the north, where they have not been explored; but they can not be traced on the other side of the valley in Red Mountain, and it is probable that they die out in the Maroon sandstones. The throw of these north-south faults varies, the Pride and Sarah Jane having a downthrow to the east, while the Castle Creek and the Schiller have a downthrow

to the west. There is, therefore, no uniform displacement, but the blocks formed between the faults have simply moved up or down to accommodate some lateral stress.

There is no definite system of east-west faults on Aspen Mountain. A few faults which have this trend are apparently local cross fractures, which have no great persistence, and whose characteristics show that they were probably developed at the same time as the north-south faults. This includes the faults on the point of West Aspen Mountain and those of the Bonnybel and Chloride group.

On East Aspen Mountain there is a system of north-south faults which is quite different in age and nature from the Aspen Mountain system. This system has its greatest development in Tourtelotte Park and is later than the ore deposition.

SMUGGLER MOUNTAIN.

In Smuggler Mountain there is no sign of any continuation of the Aspen Mountain syncline, but the beds all dip uniformly and steeply to the northwest. The amount of faulting is also greatly diminished, and the important north-south faults of the Aspen Mountain system are not found. There are, however, several minor systems of faults, which, on account of their difference in age, their great variation in attitude and in direction of throw, and because they have often all acted in the same area, are very puzzling.

Silver fault.—The Silver fault is present throughout the whole of Smuggler Mountain. In the Mollie Gibson mine, at a locality beneath the Roaring Fork Valley, it cuts out the blue limestone, and therefore obliterates the Contact fault[1] from this point north. The mines follow the Silver fault as the chief ore-bearing locality, and find all along it more or less mineralization. It is marked by a heavily brecciated zone, with solid shale and sometimes a thin band of porphyry on the west or upper side, and Leadville dolomite on the east side. It cuts down into this dolomite and nears the Parting Quartzite just before leaving the area to the northeast.

Della fault.—The Della fault has an east-west trend and a southerly dip of about 30 degrees from the horizontal. The beds on the under side of this plane are faulted to the west, and the striæ show that the actual

[1] The Contact fault runs parallel to the bedding and separates the blue limestone from the dolomite of the Leadville formation throughout a large part of the district.

movement has been to the southeast on the south side, the direction having been at an angle of 45 degrees to the horizontal on the fault plane. The perpendicular separation of corresponding beds is about 150 or 200 feet, and this separation is traceable in mine workings from top to bottom of the hill, for the dip of the fault is only slightly greater than the slope of the hill. Its outcrop can not be actually observed on the ground, for at this point there is a very thick covering of morainal material. The line represented on the map (Atlas Sheet XXVII) is calculated from the underground workings. The fault is represented on the map as dying out in the red Maroon sandstones, and this it probably does sooner or later. There are several slips parallel to the Della fault and having the same sort of motion, but in none of these is any great displacement observable. The Smuggler fault, however, which lies a short distance south of the Della, appears to become quite important in the lower part of the Smuggler and in the Mollie Gibson mine.

The age of the Della fault, and of the smaller faults which are parallel with it, is indicated by the phenomenon of ore deposition. The chief ore shoots throughout the mountain are found at the intersection of the Silver fault with the Della fault and other faults of this system, where the Silver fault is cut off by the flatter fault above. This persistent and conspicuous influence of the Della system of faults upon the distribution of the ore shows that these faults existed prior to the ore deposition. On the fault planes, however, as has been especially well observed in the case of the Della fault, there is often found crushed and broken ore, while most of the rock along these planes is entirely barren and shows no evidence that any ore has been formed there in place. The mine managers find, moreover, that the motion along the Della system of faults is still going on, as shown by the deformation of mine workings. The combination of these facts leads to the inference that while the Della system of faults existed previous to the ore deposition, the motion went on after the formation of the ores; so that in the case of the Della fault probably a large, if not the larger, part of its motion was postmineral.

Clark fault.—In the Mollie Gibson and Smuggler mines there is evidence that the ore bodies, together with the inclosing rocks and all previously formed features, have been extensively faulted by a comparatively recent movement. The evidence of this faulting is fairly conspicuous in these

mines, consisting of many nearly vertical polished and striated surfaces, which indicate a general zone of movement. The general effects of this movement were to upthrow the rocks on the east side, for in this neighborhood the dip of the Silver fault becomes much steeper than usual, on account of its continual upthrust. It seems probable that there are several, if not many, parallel slips which here diverge and there merge into one another, but they may be conveniently considered as a single fault, and in the Mollie Gibson mine, where this fault has been recognized, it has been called the Clark fault. The fact that the Clark fault is only slightly steeper than the Silver fault, which it runs very close to, and the further fact that the uplifting of the rocks on the east side of the Silver fault by the Clark fault and its dependent slips gives a slightly steeper apparent inclination to the Silver fault, make it difficult to follow and trace out in detail all of this movement. In the Gibson mine, however, it has been found that one of the main slips belonging to the Clark fault runs very close to the Silver fault, but has dolomite on both sides, thus showing that the two are not strictly parallel. The evidence of displacement is chiefly in the faulting of certain of the ore shoots in the Mollie Gibson and in the Smuggler. These ore shoots have peculiar characteristics, and hence are traceable without great difficulty. The displacement of these shoots shows that there has been a movement toward the north on the west side of the fault of 500 or 600 feet, combined with a vertical movement downward on the west side of 300 or 400 feet. Thus the actual movement was toward the north on the west side of the fault at an angle of 30 degrees or so with the horizontal, this angle being taken on the nearly vertical plane of the fault, and the total displacement was 600 or 700 feet.

North from the Smuggler mine this fault becomes still harder to trace, but near the Johnson tunnel the outcrops of Weber shales and of Archean granite seem to come suddenly very close together, so that there is no room, apparently, for the Parting Quartzite between the granite and the Silver fault. This apparent thinning of the strata at the surface, which is not found underground along the Silver fault, is probably due to the action of the Clark fault, as shown in Section A (Atlas Sheet XXVIII). Its throw is, however, represented as already diminished, and it probably grows still less toward the north. Along the top of the mountain this fault is hardly distinguishable from the Silver fault. In the Regent mine,

however, there is found along this line a marked north-south fault, nearly vertical, which has an upthrow on the east side of about 30 feet. This probably is the representative of the Clark fault. In the mapping, however, it is represented that the Clark fault, owing to its difference in dip from the Silver fault, passes into this latter fault and is lost, so that at the surface only a single fault outcrops, as indicated. The Clark fault along its entire course may be regarded as a movement which has taken place mainly along the Silver fault; locally, however, the plane of movement deviated slightly from the preexisting fault plane.

In the Mollie Gibson and Smuggler mines, where the Clark fault has operated, there is present an apparently new set of faults belonging to the Della system, along which ore has been deposited. The ore shoots were, therefore, formed subsequently to these faults (which are called, in the Mollie Gibson mine, the Gibson and the Emma), as they were formed subsequently to the Della and Smuggler faults in Smuggler Mountain proper. The movement along the Clark fault which displaced the ore shoots must, therefore, have displaced the faults belonging to the Della system, and the amount of movement, as shown by the ore bodies, is very nearly or exactly that by which the Della and Smuggler faults are separated from the Gibson and Emma. The facts seem to indicate that the Gibson and Emma faults were originally identical with the Smuggler and the Della, and that they have been separated by the cross-cutting Clark fault at the same time as were the ore bodies. Along the Clark fault in the Mollie Gibson mine the breccia contains many fragments of ore.

RÉSUMÉ OF STRUCTURE ON SMUGGLER MOUNTAIN.

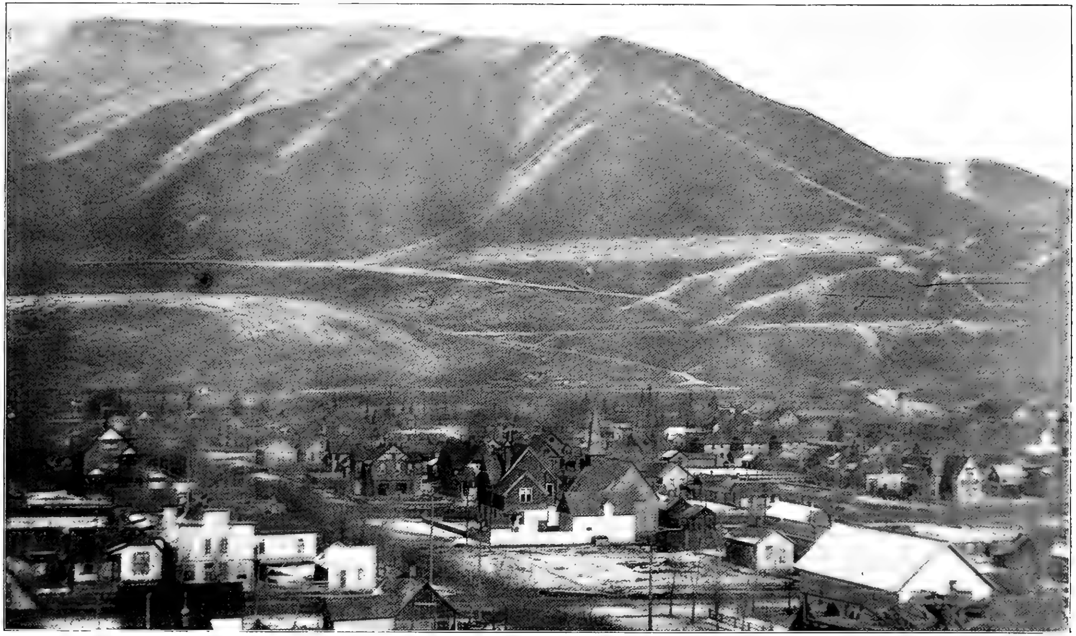
The beds on Smuggler Mountain dip uniformly and steeply to the west, and have been broken by three distinct sets of faults. The first set is represented by the Silver fault, which is nearly parallel to the bedding, and which was formed previous to the period of ore deposition and also previous to any of the other faults. The second set is represented by the Della fault, which is later than the Silver fault, as is shown by the fact that it faults this fault wherever it intersects it, and which originated previous to the ore deposition, but continued developing subsequent to that period, and is probably still growing slightly. The third set arose from movement along the plane of the Silver fault, which took place locally in planes

varying in position from that of the Silver fault. This movement, represented by the Clark fault, is therefore very nearly parallel to the bedding, and is also very close to the Silver fault, into which it probably merges both to the north and to the south. This third faulting was entirely subsequent to the ore deposition and to the Silver and Della systems of faults, both of which it faults wherever it intersects them.

RED MOUNTAIN.

This mountain, which lies immediately northwest of Smuggler Mountain and on the other side of Hunter Creek, is made up almost entirely of uniformly west-dipping sandstones and grits of the Maroon formation It offers, so far as known, no complications in geological structure. There is no folding, and what faulting may exist is obscured by the uniformity of the beds. No mineral deposits have been discovered on Red Mountain, and there is no great probability of any ever being found. There is a popular notion, however, that this mountain lies in the same belt as West Aspen Mountain, on which large deposits of ore have recently been found. This idea arises from the fact that Red Mountain is situated directly opposite West Aspen Mountain on the north side of the Roaring Fork; thus it has been supposed to have the same relation to West Aspen Mountain as has Smuggler Mountain to the eastern part of Aspen Mountain. Across Smuggler Mountain and East Aspen Mountain there is a continuous belt of mineral-bearing rocks, and the same has been thought to be true of West Aspen and Red mountains. It is clear, however, that West Aspen and Red mountains are in totally distinct geological formations, and that the correspondence in position is due to the domelike uplifting and synclinal folding of Aspen Mountain, which does not extend across Roaring Fork to the north. There has been a small amount of exploration for ore on Red Mountain, and some of the workings have cut belts which show a slight amount of mineralization, but the character of the rock is not favorable to such extensive mineralization as has occurred in the limestone and dolomites of the underlying formations.

Pl. III is from a photograph of Red Mountain taken from the foot of Aspen Mountain. The rounded or flattened summit is due to glacial action, for on top there is considerable morainal material, consisting mostly of granite and quartzite which is derived from the other side of Hunter



RED MOUNTAIN, FROM ASPEN MOUNTAIN.

Creek Valley, some distance to the east. The sides of the mountain, however, are in large part bare and afford practically continuous outcrops. Near the base of the mountain there are seen strongly marked, broad, successive terraces, which are continuous from this point down the valley for several miles. These terraces are carved out of the bed rock, but are covered and often disfigured by morainal material; it appears probable that they mark the shore lines of a lake which existed in the Roaring Fork Valley just where the town of Aspen is located. The plate also shows a typical portion of the town itself, with the Hunter Creek Valley in the right background.

DESCRIPTION OF SECTIONS.

Section A.—Section A (Atlas Sheet X) traverses Smuggler Mountain, passing through the mouth of the Johnson tunnel, and runs along the top of the uppermost and most strongly marked terrace at the base of Red Mountain. This section presents no complications in the way of folding, since all the beds have a uniform steep northwesterly dip. This dip is apparently greatest close to the granite on the east side of the section, and least in the Maroon beds on the west side. The Silver fault is seen in this section separating the dolomite of the Leadville formation from the Weber shales. There is also a thin sheet of porphyry lying at a variable but always short distance above the fault, which represents very nearly the northern termination of the main porphyry sheet. This sheet, although represented in the section as continuous, is actually crushed, broken, and intermittent, showing that it has been profoundly influenced by the effects of the fault. There is in this section none of the blue Leadville limestone, but the dolomite always lies immediately below the fault.

The Della fault is actually developed in that part of the section west of the Johnson tunnel, as is here represented, having a perpendicular separation to the west, on the north or under side, of about 200 feet. This fault displaces the Silver fault. The uplifted portion of the Della fault which appears on the east side of the Johnson tunnel is not shown underground, since there are no workings in this vicinity, but it is put in on theoretical grounds. The nearly vertical fault which displaces the Della fault is the Clark. This, also, is not actually proved, as shown in the section, but, judging from its effect in the workings of the Mollie and the Smuggler, it

must be present. In the outcrops there is along the line of this section a decided diminution in the thickness of the formations, so that the distance between the granite and the Weber shales becomes abnormally small, and there appears to be no room for the Parting Quartzite or for the Leadville formation above it. In the underground workings, however, not only the Parting Quartzite but the Leadville dolomite above is present, showing that it is not the Silver fault which has thus cut out the Parting Quarzite in outcrop. The way in which the Clark fault has probably produced this local narrowing of the outcrop is shown in the section, and the explanation is based on its actual movement as displayed in the Mollie Gibson and Smuggler workings. The downthrow of this fault on the west is shown in the sections as about 300 feet, but it will be remembered that the actual displacement is downward to the north on the west side of the steep, slipping plane, at an angle of about 30 degrees to the horizontal. Westward from the Silver fault to the end of the section there is nothing, besides the porphyry already described, but Weber shales and the sandstones, limestones, and grits of the Maroon formation.

Section B.—Section B, Atlas Sheet X, runs northwest from the summit of East Aspen Mountain across to the ridge at the northern termination of West Aspen Mountain, and so across Castle Creek into the Roaring Fork Valley and out of the area.

At the eastern end of the section the beds are seen to have a shallower dip than at a little distance farther west. This shallowing of the dip is indicative of the approach to the anticlinal structure which has already been noted as sometimes occurring to the east of the main syncline. From the top of East Aspen Mountain the dip steepens steadily toward the west for a while, then suddenly flattens on approaching the bottom of the Aspen Mountain syncline. At the point where this steep dip of the eastern limb of the syncline changes to the flat dip at the bottom of the fold there are several slight slippings and faultings developed, of which the Aspen fault is the most important, and is the only one represented in the section. This fault has a slight downthrow to the east, not noticeable in this section; it probably runs into the Silver fault, and therefore its upper part is lost. The Silver fault is shown separating the porphyry from the Leadville formation, with a thin, variable band of broken shale between; the actual contact is between shale on the west side and the blue Leadville limestone

on the east. This blue limestone makes its first appearance in the space between Section A and Section B, under the Roaring Fork Valley, as shown in the Mollie Gibson workings. South of this point it always lies below the Silver fault, while to the north it is as uniformly absent. The Silver fault is downfaulted beyond the scope of the section by the Schiller fault, and continues below the plane of the section as far as the Pride fault, when it is upfaulted so far that it has been entirely removed by erosion on West Aspen Mountain. The Mary B. fault throws down the rocks on its west side so that the Silver fault is again brought far below the plane of the section, and the Castle Creek fault thrusts it down still farther. It is visible, therefore, only in a narrow strip between its outcrop in Vallejo Gulch and its termination against the Schiller fault.

In this section the Schiller fault has a heavy downthrow on the west side of about 600 feet, while the Sarah Jane fault, lying next west, has its usual slight downthrow on the east of about 200 feet. The Pride fault has a throw of about 2,000 feet, so that on the east side of the fault at its outcrop are Weber shales, and on the west is granite. The section next passes diagonally through the point of West Aspen Mountain. The obliquity of the section makes it appear as if the beds on West Aspen Mountain were dipping away from the Aspen Mountain syncline, while in reality they have a general dip toward it, although the actual dip is more to the north than to the east.

The east-west northerly dipping faults of West Aspen Mountain are also shown in the section, and the Mary B. fault is cut not far from its junction with the Castle Creek fault, a little distance to the south. Here the basal limestone of the Maroon comes in just above the contact with the Weber. At the Castle Creek fault the easterly dipping reversed red sandstones of the Triassic come in and are continuous to the end of the section, except where covered with wash. As shown in the section, the Mary B. fault has a downthrow on the northwest side of about 2,000 feet, while the throw of the Castle Creek fault, as roughly estimated by the distance from the middle of the Triassic to the bottom of the Maroon, is 5,300 feet or more.

Section C.—Section C (Atlas Sheet X) cuts across the southwest corner of the Aspen special map, parallel with and only a short distance from Section B. As in Section B, the plane crosses the Aspen Mountain syncline at an angle, so that the northerly pitch of the syncline causes the general inclination

of the beds to the northwest, as seen in the section. The features of the section are nearly like those of Section B. The northerly pitch of the Silver fault carries it, with the associated beds, into the section for the whole distance from its point of outcrop on the east side of Vallejo Gulch to the granite on the west side of the section. It is upfaulted on the west side by the Saddle Rock fault, so that it outcrops in the plane of the section, and is again upfaulted to the west by the Pride fault so as to be carried up into the air and lost. The Aspen fault is shown with its slight, peculiar downthrust on the east side. The Schiller fault, which is here nearer its termination than in Section B, is shown with a throw of less than 200 feet. The Sarah Jane fault has about its usual downthrow of 250 feet to the east. The section cuts the Saddle Rock and Pride faults just south of their point of junction, at a point where they are very close together. The throw of the Saddle Rock fault is shown as about 1,100 feet down to the east, while that of the Pride fault can not be actually measured, since the granite on its west side does not afford a definite horizon, but it is 1,200 feet at least. From the Pride fault to the Castle Creek fault there is nothing but granite, for the northerly dip of the beds at the northern termination of West Aspen Mountain carries them up into the air, so that only granite outcrops over the whole southern part of the ridge. At the Castle Creek fault, as in Section B, the overturned Triassic sandstones come in and continue to the end of the section.

RÉSUMÉ OF STRUCTURE SHOWN ON THE ASPEN SPECIAL MAP.

First. The first deformation in the rocks, changing them from their original structure, was folding, which is partly illustrated by the monoclinal, steeply dipping strata of Section A (Atlas Sheet X).

Second. Probably contemporaneous with this folding there occurred a slipping of different layers one upon the other, producing a system of faults nearly or quite parallel with the bedding, of which the Silver fault is the most important representative. These faults follow in a general way the folding in the rocks, and are faulted by all the other fault systems.

Third. At some early stage in this deformation there took place a local uplifting of the rocks, including the sedimentary formations and the underlying granite, which produced a marked and abrupt domelike structure. There is reason to believe that this took place at a somewhat later

date than the regional folding. This uplift was due to local disturbing forces, and seems to have been contemporaneous with the initiation of the first fault systems.

Fourth. There originated a system of faults having a general north-south trend and in general a nearly vertical dip. The greatest of these is the Castle Creek fault, and from this toward the east the parallel faults grow successively less in importance till the system dies out before reaching East Aspen Mountain. All of these faults are characterized by having their greatest development on Aspen Mountain, from which point they diminish in throw to the north and to the south. Several of them have very great displacement, and they all were almost entirely developed previous to the deposition of ores, for it is along them that much of the ore has been found. This system is, however, of younger age than the Silver system of faults, since it faults this latter system in the same way that it does the inclosing rocks. To the Aspen Mountain system, also, belong certain nonpersistent cross faults, which, however, have often considerable throw. Such are the faults at the north end of West Aspen Mountain, and those of the Bonnybel and Chloride system. Their probable identity in age with the main north-south faults is shown by the fact that they also are highly mineralized. It appears probable that this system of mainly north-south premineral faults was developed at about the same time that the doming-up of the rocks on Aspen Mountain occurred, and that the phenomena of faulting and folding are both manifestations of the same upthrusting power.

Fifth. The faulting which has thus been described apparently continued during and after the period of ore deposition. The Della system of faults on Smuggler Mountain evidently existed previous to the period of ore deposition, for it is along these faults, at their junction with the Silver, that much if not most of the ore on Smuggler Mountain has been deposited. The barrenness of much of the slipping planes, however, and the fact that along these barren planes there are often fragments of hard ore found in the breccia, show that much of the movement has gone on subsequent to the ore deposition; and, indeed, it is probable that the faults in some cases have had their main development since that period. There is also evidence that the movement along these faults is still going on, this evidence being derived from the deformation of mine workings. These faults, which have

an east-west trend and a flat southerly dip, therefore belong to a somewhat later period than the Aspen Mountain system.

Sixth. On East Aspen Mountain there are found the representatives of a system of north-south and in general vertical faults, which has its main development in Tourtelotte Park. From this point of maximum development the system dies out to the north and to the south. So far as can be judged it is entirely later than the ore deposition, and therefore later than the Della system. The Clark fault on Smuggler Mountain may be included in this last system.

TOURTELOTTE PARK SPECIAL MAP.

The general attitude of the formations on Aspen Mountain undergoes a marked change to the southward, so that the strike changes from east to northeast and finally swings round and becomes permanently north. This change is evidently antecedent to the faulting which forms such a conspicuous part of the geology in this region. The main features of folding are the same in the Tourtelotte Park district as in Aspen Mountain, but they are less accentuated. The deep broken syncline of Aspen Mountain is continuous into the north end of the Tourtelotte Park special area, but becomes continually shallower toward the south, until at about the southern end of the Tourtelotte Park mining district it has virtually disappeared. The flattening of the beds on East Aspen Mountain is also continuous into the Tourtelotte Park district, where it is developed into an anticline, which is in many places obscured by subsequent faulting. There also appears in the Tourtelotte Park area a second syncline to the east of the anticline, which lies next the granite; but in many places this syncline has been uplifted by faulting and removed by erosion. These gentle folds become less marked toward the south, and finally die out. The line of the Castle Creek fault is not strictly parallel with that of the contact of granite and sedimentary rocks, but the two lines converge toward the south, so that the width of the belt occupied by the lower stratified rocks becomes continually less. The rocks to the west of the Castle Creek fault have an entirely independent structure, so that the gentle anticline and syncline referred to are gradually cut out by the encroachment of the Castle Creek fault. The main anticline, whose axis practically coincides with the divide between Roaring Fork and Castle Creek throughout the

whole extent of the Tourtelotte Park special area, becomes in its turn a gentle monocline, dipping into the Castle Creek fault, and in the southernmost part of the area the remnant of this anticline is united with the easternmost syncline to form a single simple monoclinal structure.

Within this district, bounded on the west by the Castle Creek fault and on the east by the granite, there is an excessively complicated system of faulting. The faults may be separated into various distinct systems, but all have apparently an interdependence. A very conspicuous system runs nearly parallel to the Castle Creek fault and to the contact of granite and sedimentaries, and therefore nearly parallel to the longest axis of the wedge-shaped area included between these two boundaries. Another, weaker, but not less conspicuous, system runs at right angles to the first, parallel to the shortest axis of the area. Wherever these faults intersect the Castle Creek fault, as is often the case with the east-west system, they usually seem to disappear. Occasionally, however, an east-west fault seems to displace the Castle Creek fault, thus showing its later age; but even in this case the cross-cutting fault probably disappears a short distance away from the Castle Creek fault to the west.

On the western side of the main Castle Creek break there is no evidence of any such complicated system of intersecting faults as is found on the east. There is, however, a system of faults which are nearly parallel with the main Castle Creek break and which are evidently dependent upon it; but these faults are quite distinct in nature from the Tourtelotte Park types. In the great mass of Maroon and Triassic sandstones immediately west of the Castle Creek fault, and also in the Weber shales and limestones which occur on the west side of the fault in the southern part of the Tourtelotte Park special area, it is hard to distinguish slight faulting, owing to the similarity in lithological composition of the beds through great thicknesses; but from all the data that can be obtained it seems that the Tourtelotte Park type of faults is either absent in these beds or has become so unimportant as not to be easily recognized.

On the eastern side of the Tourtelotte Park special area the contact of the granite with the overlying beds constitutes an effectual barrier to further investigation of structure. It is probable that many of the faults are continuous into the granite for indefinite distances, for the faulting along the contact of granite and Cambrian quartzite is often very strong

and complicated. Once past the line of contact, however, we have no method of ascertaining the number, system, or amount of throw of these faults, or any positive proof of their existence, so that the faulted area to be studied must be considered as essentially comprised between the Castle Creek fault and the granite-quartzite contact.

The amount of disturbance which has taken place in this area, as indicated by the occurrence of these numerous intersecting faults, is apparently greater in the northern part of the Tourtelotte Park special tract, or in about the area occupied by the Tourtelotte Park mining map (Atlas Sheet XXI), than in any other part of the entire district examined in the course of the survey. The southern part of the Tourtelotte Park special tract has a similar but somewhat less complicated system of faulting, and the two halves of the tract may be conveniently considered as representing slightly differing areas. These two areas may be separated at the line of the Butte fault, which traverses the whole district from east to west.

The faults of the northern half show a continuation of the characteristics of those of Aspen Mountain, together with the development of new features. The most characteristic of the Aspen Mountain faults gradually die out in the Tourtelotte Park district, while faults which are unimportant on Aspen Mountain, or which are even totally absent, become well marked and important in Tourtelotte Park. Thus the great north-south break called the Pride fault, which on Aspen Mountain splits into two branches, diminishes in importance gradually toward the south, so that the throw becomes comparatively slight in the Tourtelotte Park district. On the other hand, there is another system of north-south faults, which is parallel with the system of the Pride and the Saddle Rock, but which has its greatest development in Tourtelotte Park and becomes continually less important toward the north, finally dying out or merging into the Silver fault. To this class belong the Justice and Copper faults, also the Ontario and other parallel breaks which are exhibited to the east of the Copper fault. This second system is apparently younger than the system represented by the Pride, Sarah Jane, and allied faults. It is evident that the former system has developed mainly subsequent to the period of mineral deposition, while the Pride or Aspen Mountain system must have been nearly completed before the deposition of the ores, since it is along these faults that the ores are most conspicuously formed. The younger system, however, which is

represented by the Justice, is not mineralized; but the faults belonging to this system fault the ore bodies as well as the inclosing rocks. The faults belonging to the Justice system have apparently a maximum throw close to the topographical basin which was originally denominated Tourtelotte Park; from this point they disappear gradually toward the south, and more rapidly toward the north, so that they are comparatively unimportant or wanting in the Aspen special area, and diminish in importance in the south half of the Tourtelotte Park special area. A common accompaniment of such diminution toward the north is a change in trend, which veers from north to northwest, so that the faults of this system approach the Silver fault.

Running directly across the north-south faults is a system of east-west faults, which are of much less persistence. Sometimes they traverse only the space between two adjacent north-south faults; sometimes, however, such a fault traverses two or three north-south faults; and the Butte fault, which is a member of this system, cuts through the entire district, even across the Castle Creek fault. The intersection of the east-west faults with the north-south faults produces a system of blocks; and these blocks have been moved one upon the other, so that the resultant structure becomes very complicated. Such blocks may have an independent movement which is not partaken of by any of the adjoining blocks; again, two or three blocks, or even more, may have moved together, having a uniform amount and direction of movement with reference to the adjacent mass. The study of these faults has made it appear, moreover, that the movement, instead of taking place at one time, went on gradually for a very long period, so that at a certain stage a block has apparently moved independently with relation to the surrounding blocks and at a different time has united with the surrounding blocks in some more extensive movement. The result of this continual up-and-down shifting of the minor blocks is that the throw of any persistent north-south fault which traverses these blocks varies considerably from place to place, although the general movement of this larger fault remains ordinarily the same under all conditions.

The more important faults will now be described separately, in order that the peculiarities of each may be understood as they appear upon published maps, and in order that the general structure of the district may be more thoroughly presented.

Silver fault system.—To this system belong a number of faults which are nearly or quite parallel to the bedding of the strata in which they occur. There are many of these found in nearly all of the formations in the district, but certain ones are so persistent and continuous that they can be easily traced for considerable distances. One of these faults, called the Contact fault, occurs between the blue Leadville limestone and the underlying dolomite. As far as can be seen, it does not cut across the beds, but runs strictly parallel to them, thus nearly always forming a true division between the two members of the Leadville formation. This fault has not been shown on the 800-foot map or in the 800-foot sections, but is found always at about 250 feet above the bottom of the Leadville formation. In the 300-foot sections made across the Tourtelotte Park mining map the Contact fault is shown, as determined by outcrops and mine workings.

A still more important fault may be called the Silver fault. This occurs at a horizon only about 150 feet, or often not more than 100 feet, above the Contact fault, and usually has, in this district, the blue Leadville limestone on one side and the soft shales of the Weber formation on the other. Developments in the mines show that there has been an immense amount of movement along this fault, resulting in the formation of a breccia made up of the limestone, shale, and porphyry, which is often as much as 50 feet thick. It seems that the effect of this fault in the Tourtelotte Park district has been to reduce the thickness of the shale below the porphyry. From sections in other places it appears probable that there was an original thickness of about 250 feet of shale between the porphyry and the limestone, while in the Tourtelotte Park district there lies between the two only about 50 feet of shale, generally crushed and broken, and even this is sometimes wanting, so that the porphyry rests directly against the limestone.

The Silver fault is shown in the 800-foot map and sections. It crops continuously on both sides of the main ridge to the west of Spar Gulch in Tourtelotte Park, dipping slightly into the hill east and west on either side with the strata which form the continuation of the Aspen Mountain syncline. Inasmuch, however, as this syncline retains its northerly pitch, which is steeper than the surface slope, the outcrop of the Silver fault becomes higher and higher, so that it finally passes above the surface, and is not found at all in the southern part of the district. The Contact fault, since it lies a short distance stratigraphically below the Silver fault, persists a little farther to the

south, but this also passes above the surface a short distance south of the central part of the district, and, like the Silver fault, is not found farther south. Since these two faults are among the most important factors in determining ore deposition, it may be understood why the southern part of the Tourtelotte Park special district to the east of the Castle Creek fault is practically barren.

The fact that the Silver system of faults has been more than anything else the locus of ore deposition, shows conclusively that the faults originated before the mineralization. The fact that all the other systems of faults, both postmineral and premineral, have displaced the Silver system in precisely the same degree as they have the adjacent strata, indicates that the Silver system was formed at an earlier period than the others, and it may be supposed that it was contemporaneous with the folding of the strata, being the result of the slipping of one bed over the other in the course of plication.

Castle Creek fault.—The Castle Creek fault is definitely traceable throughout the whole length of the Tourtelotte Park special district. Beginning at the north and following its outcrop south, it may be found separating the red Maroon sandstones from the Archean granite on the mountain side between Keno and Ophir gulches; southward it is distinctly shown in Ophir Gulch; from there it is traceable across the intervening ridge into Queens Gulch. It then runs southeast in the very bottom of this gulch for some distance until the gulch curves abruptly east, as shown on the topographical maps. At this point the fault does not turn with the gulch, but continues on, finally leaving the district close to the Surprise shaft. Through the whole distance the fault is shown on the surface by outcrops and underground by tunnels.

At the point where the Castle Creek fault crosses Ophir Gulch there are red Maroon sandstones on its west side, with granite on the east. In the bottom of the gulch, however, come in narrow wedges of porphyry and Weber shale, rocks which underlie the Maroon sandstones on Red Mountain and the rest of the district. These wedges of porphyry and shale widen toward the south, until at the southern limit of the district nearly the entire normal thickness of Weber and of porphyry outcrops. Although these formations are very nearly in their normal position, their thinness at the northern end of their exposure and their contact phenomena show that they are brought into position by faults which are nearly parallel to the Castle Creek fault and are dependent upon it. Since the general dip of

the beds of the west side of the Castle Creek fault is nearly parallel with the dip of the fault itself, it follows that these slips are nearly parallel with the beds which they traverse. Their action is to bring up wedges of the different formations against the Castle Creek fault sooner than these formations would come up with the normal structure. The dip of the faults, however, is not exactly coincident with the dip of the beds; the blocks brought up, therefore, are wedge shaped, and in cutting across such a series of slips the various formations are encountered in their normal order, but usually very much reduced from their normal thickness, and are locally sometimes entirely absent. This structure is shown in the Dubuque tunnel in Queens Gulch, which cuts across the steeply dipping beds on the west side of the fault and finally crosses the fault itself into the granite. In passing through this tunnel, which is over 800 feet long, the first solid rock encountered is the gray micaceous limestone, which is recognizable throughout the district as lying at the base of the Maroon formation. Beyond this is a considerable thickness of black Weber shales; then comes a large mass of porphyry, which in turn gives way to another body of shale. Near the end of the tunnel, just before reaching the granite, there is a highly altered and mineralized zone, which has apparently all the characteristics of altered blue limestone of the Leadville formation. This succession is that normally found going downward from the base of the Maroon to the top of the Leadville formation, although in this place the beds are dipping steeply to the east and are therefore locally overturned and in the reverse of their usual position. Although the succession is normal, the thickness of the various formations is much less in this section than usual, as is shown by comparison with the beds on Red Mountain and on the ridge south of Queens Gulch. The Weber shale, for example, which lies between the porphyry and the Maroon gray limestone, and which normally has a thickness of not far from 1,000 feet, is here only about 200 feet thick. The porphyry, of which there should be normally 300 or 400 feet, is here only about 200 feet thick, while the shale underlying the porphyry, which is normally 250 feet thick, is here 100 feet or less. The mineralized zone which has been taken as altered blue limestone is a narrow strip along the fault, averaging 50 or 60 feet, while the normal thickness of the Leadville blue limestone is about 150 feet. The contacts of these various formations, as exposed in tunnels, are always greatly brecciated, showing that they are

true fault contacts. These dependent faults, however, are active only in the immediate vicinity of the Castle Creek fault, so that when the normal dip of the beds brings the porphyry and the Weber shales to the surface, and the divergence between the strike of the beds and the trend of the Castle Creek fault causes a separation of these beds from the fault, their thickness seems to be normal, and not increased or diminished by any dependent faulting.

Since the elevation of the hills is greater at the southern end of the Castle Creek fault as exposed on the Tourtelotte Park special map than it is on the north end, and since in spite of this fact the beds which are exposed on the western side of this fault belong to horizons growing successively lower southward, it follows that there has been a marked elevation of the beds in the southern part compared with those farther north. On the east side of the Castle Creek fault, however, the reverse is true; for southward are successively higher and higher formations. In the northern part of the area mapped, for example, there lies on the east side of the Castle Creek fault a great body of granite. On going south along the fault, one passes in the neighborhood of Ophir Gulch from granite into the overlying quartzite, which here comes into contact at the surface with an uplifted wedge of Weber shales; farther south one passes from quartzite into Silurian dolomite, which in the neighborhood of the Dubuque tunnel outcrops on the eastern side of the fault, abutting against shale or quartz-porphyry on the western side. The more recent Butte fault has so operated that south of here the Cambrian quartzite again outcrops along the east side of the fault for some distance. During most of the distance that the Castle Creek fault runs in Queens Gulch it has this quartzite on the east, with the Weber shale becoming very thick on the west. Near the head of Queens Gulch the rocks on the eastern side of the fault change from Cambrian quartzite back into Silurian dolomite; farther up the dolomite gives way to diorite-porphyry, which in turn is replaced by the dolomite belonging to the Leadville formation, so that at the limit of the mapped area on the south the fault separates Leadville dolomite from quartz-porphyry. This succession of beds on the east side of the fault shows that there has been no such tilting as occurred on the west side. If any tilting has occurred it has been exactly the reverse, and the southern part of the district has undergone a slight depression as compared with the northern part.

In the southern part of the area of the Tourtelotte Park special map the effect of this elevation of the beds on the west side of the fault and the corresponding depression of the beds on the east side is to diminish the throw very rapidly toward the south. Thus the amount of displacement near the southern end of the area appears to be about 2,600 feet (see Section F, Aspen district map, Atlas Sheet VII); in Queens Gulch the displacement is about 6,300 feet; while at the northern end of the area it is probably as high as 8,000 feet (see Section D, Aspen district map).

The diminishing of the Castle Creek fault is accompanied by a corresponding dying out in intensity of the associated folding. The close overthrown fold which is shown at Castle Butte and at the western base of Aspen Mountain becomes progressively more open toward the south, and the easterly dip of the overturned beds becomes progressively steeper. In Keno Gulch the red sandstones dip toward the east at an angle of 45 or 50 degrees; in Ophir Gulch, however, the beds dip east at an angle of about 70 degrees. At about the point where the fault enters Queens Gulch the beds become actually perpendicular; southward from this point they assume a westerly dip, thus marking the end of the overthrown fold; and from this point on the beds lie in their normal succession, always dipping to the west at an angle which grows less toward the south. The close overthrown fold of Aspen Mountain is thus replaced by an extensive open fold, several miles in width. The fact that the fold shows signs of dying out in the lower formations and becoming more complicated in the upper ones, being very much less in the lower Maroon and Weber beds of Queens Gulch and vicinity than in the Cretaceous beds of Red Butte, may indicate that in the original fold the amount of deformation was greater in the upper beds than in the lower throughout the whole of the district, and that if erosion in the vicinity of Red Butte should reveal the underlying formations corresponding to those exposed in the vicinity of Queens Gulch there would appear in these formations a much simpler folding than occurs in the beds actually exposed. From this point of view the beds west of the Castle Creek fault form an overthrown fold, whose axis pitches northward. Erosion, acting more vigorously on the uplifted portion, has stripped the fold fault down to near its roots in the southern part of the district mapped, and quite down to its roots where the fold and fault merge into the granite at a point not far south of the limits of the map.

Corresponding with the steepening toward the south of the easterly dipping beds on the western side of the fault is a steepening of the fault plane itself. While in Keno Gulch it appears to be 45 or 50 degrees to the east, as shown in tunnels, in Queens Gulch it is as much as 80 or 90 degrees to the east. At the extreme southern end of the district it has become nearly vertical, with still an easterly tendency. If we consider, as has been suggested, that at the southern end of the district are the roots of an original overthrown fold, which culminated in the faulting, then the gradual steepening of the fault plane toward the south shows that the main fault has a curved form, becoming steep and possibly overturning in depth, while in the higher formations it has a dip approximately corresponding with the main axis of the overthrust fold, and consequently with the dip of the strata.

Saddle Rock fault.—This name is given to the eastern of the two branches into which the Pride fault splits on West Aspen Mountain. The Pride fault itself, as has been stated, has a downthrow to the east of about 2,000 feet, and is thus, since it has a very steep dip to the east, a normal fault. After it splits into two branches its throw is divided. The Saddle Rock fault is continuously traceable from the area of the Aspen special map into that of the Tourtelotte Park special map.

In Section A, Tourtelotte Park special map (Atlas Sheet XIII), the throw of the Saddle Rock fault is shown to be about 500 feet; in Section B, farther south, it is about 300 feet; in Section C it is about 200 feet; in Section D about 100 feet, and in Section E about the same. These figures show a constant diminution in throw, and it is probable that the fault dies out in the southern part of the area mapped or merges into the Castle Creek fault. The explanation of this diminution of throw in the Saddle Rock fault is the same as for the Castle Creek fault, namely, a differential movement consisting of a slight elevation of the southern end of the district on the east of the fault, and a marked depression on the west side. Thus, in going along the western side of the fault from the northern edge of the district toward the southern, we pass from the Archean granite up into the Cambrian quartzite, and from this into the Silurian dolomite. This dolomite outcrops in the neighborhood of the Saddle Rock shaft. On the eastern side of the fault, however, there is no change in formation in going this distance, so that while at the northern edge of the district the fault

separates the blue Leadville limestone from the granite, near the Saddle Rock shaft it separates the same limestone from the Silurian dolomite. Still farther south this differential movement causes the faulting to become so slight that on the mountain side above Queens Gulch there appears to be Silurian dolomite on both sides of the fault.

Along this fault, both in Aspen Mountain and in Tourtelotte Park, there has been considerable mineralization, showing that the fault is older than the ore deposition.

Sarah Jane fault.—The Sarah Jane fault runs close and parallel to the Saddle Rock fault; it is apparently of the same age, and has the same characteristics. Like the Saddle Rock, it has formed an important locus for the deposition of ores, and like the Saddle Rock, its movement becomes progressively less toward the south, while on Aspen Mountain, as above noted, it has its maximum throw. This throw, however, diminishes much more rapidly southward than does that of the Saddle Rock fault. In Section A of the Tourtelotte Park special map (Atlas Sheet XIII) the throw seems to be only about 150 feet; in Section B it is only about 100 feet. In Section C it appears from the map to have increased to about 300 feet, but this apparent increase is due to a local downthrust of the rocks east of the fault, in the wedge between the Sarah Jane and Justice faults. Just south of Section C, however, the Sarah Jane and Justice faults finally come together, and the wedge between them disappears; these faults, after uniting, seem to have only a very trifling amount of disturbance, and are not definitely traceable any great distance to the south.

Justice fault.—The Justice fault is so called because of its chief development in the Justice mine in Tourtelotte Park. This is the first north-south fault of any consequence to the east of the Sarah Jane. It does not, however, belong to the same general series as do the Saddle Rock and Sarah Jane faults, and presents certain marked characteristics which put it into a different class. Instead of having its greatest development on Aspen Mountain and a diminishing throw to the south, it has its greatest development in Tourtelotte Park itself, whence its throw diminishes both to the north and to the south.

In the park its maximum movement seems to be a downthrow of about 400 feet to the east (Section B, Tourtelotte Park special map). South of this the throw diminishes rapidly, so that the null point is apparently

reached in the southern part of the topographical basin known as Tourtelotte Park. In Section C, Tourtelotte Park special map, the Justice fault appears to have an upthrow to the east of about 100 feet, but this is only local and is owing to the downfaulting of a narrow wedge-shaped block included between the Justice and Sarah Jane faults, near the point where they converge and meet. The effect of the downfaulting in this block is to reverse the throw of the Justice fault, and to give the Sarah Jane an increased downthrow of 100 feet or so. Beyond the point where the Sarah Jane and Justice faults meet, neither can be traced any great distance to the south, and it is probable that both die out soon after uniting.

To the north of the point of greatest development of the Justice fault there is a more gradual dying out of the throw, and the fault runs in the bottom of Spar Gulch to Copper Gulch, where it unites with the Copper fault and with what is known on Aspen Mountain as the Chloride fault. The Chloride fault, as exhibited in the Bonnybel mine, has a northwest trend and a southwest dip, and a downthrow to the northeast of 100 feet or more. Both the Justice and the Copper faults, but especially the latter, have diminished materially in throw by the time they come together.

The displacement of the Justice fault in Spar Gulch is always a normal downthrow to the east, except where the movement has been complicated by east-west faults of later origin. On account, also, of these complicated east-west faults the average movement of the Justice is hard to determine, but it seems to be about 250 feet in Spar Gulch.

The Justice fault belongs to a different system from the Saddle Rock, Sarah Jane, and other faults belonging to the Aspen Mountain series. While the faults of the Aspen Mountain series have been important loci of mineral deposition, the series represented by the Justice fault has undoubtedly developed since the ore deposition. Apparently no ores have formed in place in connection with this latter system, but the faults have displaced the preexisting ore bodies, together with the inclosing formations.

Copper fault.—The Copper fault has been given its name from Copper Hill, on the east side of which it runs. Copper Hill, in turn, has obtained its name from the Copper King shaft, which is situated on the top of the hill; but the name in either case does not imply any great abundance of the metal. This fault is one of the north-south series, and runs very nearly parallel to those already described. It has the characteristics which have

been referred to in the case of the Justice fault, and therefore belongs to the Tourtelotte Park or postmineral system rather than to the Aspen Mountain or premineral system. Its greatest displacement is very close to the corresponding displacement in the Justice, being on the edge of the Tourtelotte basin.

In this place it has an upthrow to the east of about 400 feet; but northward the throw diminishes with comparative rapidity. It is normally an upthrow to the east, but locally (see Section A, Tourtelotte special map, Atlas Sheet XIII) there is a downthrow to the east in consequence of faulting produced by the later east-west faults. Toward the north, also, the dip of the fault, which at the point of its maximum throw is apparently quite steep to the west, becomes progressively flatter, causing the approach of its outcrop toward that of the Justice fault, until, at the junction of Copper and Spar gulches, the two faults unite. It may be observed that for a considerable distance above the line of the junction of these two gulches the faults lie directly in the beds of the gulches and that the gulches themselves have been determined by the faults. As the Copper fault nears the point of junction with the Justice fault, the flattening of the dip of the fault combines with the decrease of the throw to cause the apparent displacement to become comparatively insignificant, so that at the point of junction with the Justice fault it has already nearly died out.

South of the point where the fault has its maximum throw in Tourtelotte Park there is the same phenomenon of swift diminution as in the case of the Justice. The Copper fault was not traced beyond the Butte fault, and probably does not continue very far beyond this point.

Ontario fault.—The Ontario fault is so called because it lies at a point on the hillside a short distance above the Ontario tunnel, although it does not actually cut it. This fault has the same general characteristics as the Justice and Copper faults, so that it has been classified with the Tourtelotte Park system rather than with the Aspen Mountain system. Like the Justice and Copper faults, it has a maximum throw in Tourtelotte Park, from which maximum it diminishes rapidly in both directions. Like these faults, also, its prevailing movement is a downthrow to the east; and like them it is younger in age than the ore deposition, and is therefore a postmineral fault. Its maximum throw occurs about the middle of the area of the Tourtelotte Park special map, being a downthrow to the east of about 1,00) feet (see

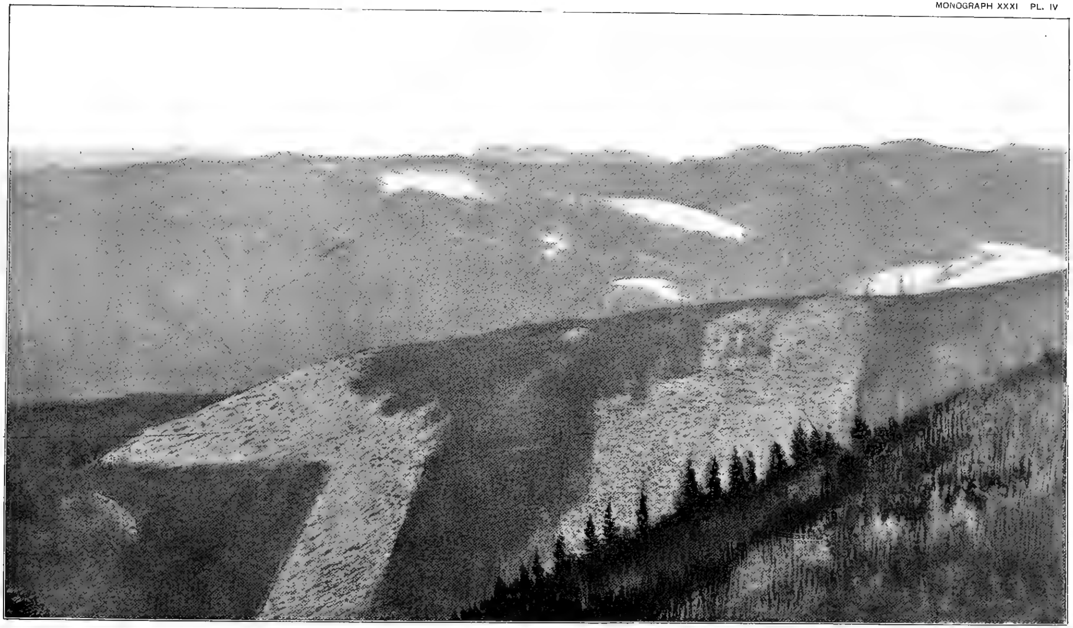
Section D, Atlas Sheet XIII). On Section B to the north and Section E to the south an equal apparent displacement is exhibited, the downthrow measuring about 800 feet. Between Sections B and D there is apparently a block in which the Ontario fault is not developed. This block lies between the Butte fault and the next east-west fault to the north. This east-west fault is apparently a continuation of the Good Thunder fault of Tourtelotte Park, but has a much greater throw. On the south side of this block, however, the outcrop of the Ontario fault reappears in exactly the same line, with the same amount and direction of throw as on the north side. There can, therefore, be no doubt that it is the same fault. The reason why the fault does not outcrop in the block above referred to is not quite evident. Exposures are not very abundant in this intervening space, but so far as they are present they seem to consist entirely of granite, which shows that the Ontario fault is probably absent. It is possible, however, that the fault may actually exist with a diminished or locally altered displacement. To the north of Section B the fault may be continuously traced out of the area of the Tourtelotte Park special map into that of the Aspen special map, where it is found running nearly along the crest of East Aspen Mountain. Between Sections B and A, however, the single fault seems to split into several parallel faults, which divide up the total throw between them, so that in Section A the displacement of that fault which is apparently the continuation of the main Ontario fault entails only about 100 feet downthrow to the east. In the same sections, however, there appears a second parallel fault, farther to the east, which is evidently closely associated with the main fault. This second fault has a downthrow to the east of about 500 feet, so that the two together make up a downthrow of about 600 feet, which is the displacement that might naturally be expected. Farther to the north there appear (still in the area shown on the Tourtelotte Park special map) three such faults, which are continuous into the area of the Aspen special map. In that area these faults rapidly die out, and their displacement is additionally complicated by east-west cross faults. In the blocks produced by the intersection of these cross faults with the main north-south faults the disturbance has often brought about tilting, reduction of the amount of displacement, or even reversal of the normal movement. These disturbances tend to counteract each other, so that on the north edge of the crest of East Aspen Mountain the aggregate displacement has become comparatively

slight, and probably nearly dies out on the northwestern slope of the mountain. At this point the north-south faults of the Ontario system swerve to the northwest from the north and approach the Silver fault.

Owing to the diminution in throw of the Ontario fault toward the south, at the southern edge of the Tourtelotte Park special map (Atlas Sheet XII) the downward throw to the east is only about 250 feet, as shown in Section F. If the throw continues diminishing at this same rate the fault must entirely die out in a short distance.

Butte fault system.—The Butte fault is in some respects the most important and persistent of a numerous class of parallel faults which are well developed in the area represented by this map. It has already been remarked that in some respects the area may be divided into a northern and a southern district, separated by the Butte fault. Keeping this arbitrary division in mind, it may be observed that the east-west faults of the Butte system are considerably more numerous and important in the northern part than in the southern. In the southern part there seems to be a comparative uniformity in the displacement, which is mostly a successive downthrust of the blocks between them to the south. In the northern half, however, there is no great uniformity in the displacement. The faults are more numerous and heavier than in the southern part, and the blocks inclosed between them have been irregularly shifted up and down. The Butte fault, which has been taken as the dividing line between these two slightly differing districts, partakes of the peculiarities of the southern part, having a maximum upthrust to the north of about 400 feet. As is shown by the north-south sections, the throw of the Butte fault is diminished on the main ridge directly south of the Tourtelotte Park basin (see Section H, Atlas Sheet XV) to 50 feet; but this diminution is due to independent movement of neighboring blocks in this much agitated area, and the throw as measured in Sections G and I is rather to be taken as the normal one.

In this northern part of the Tourtelotte Park area the east-west faults are much more numerous and important than anywhere else in the whole district. Their intersection with the several north-south faults has produced many separate blocks. In the movement which has apparently gone on since the formation of these blocks each one seems often to have had an independent action, sliding up or down without any great dependence on the motion of the adjacent masses. Since in this district the strata do not



FAULTING OF CAMBRIAN QUARTZITE AND SILURIAN DOLOMITE ON HILL ON EAST SIDE OF COPPER GULCH.

have steep dip, but are flat when compared with the dip of the beds on Aspen and Smuggler mountains, the resultant surface geology as now exposed by erosion is rather more complicated than anywhere else, and in many places presents a confused checkering. Were it not for the fact that the erosion of the glaciers has usually stripped these surface rocks and left them comparatively bare, it would be often impossible to decipher the structure; but fortunately the outcrops are very numerous in some of the most complicated places. A good example of this is the geology of the hill just east of Copper Gulch, near the extreme northern edge of the area mapped. Pl. IV is a view of this hill from across Spar Gulch, and at that distance shows how the complicated geology is sketched out on the side of the hill as on a map. The hill referred to lies in the foreground of the picture. The reader, on viewing the plate, is looking toward the east, and the left-hand side of the picture corresponds very nearly to the northern end of the Tourtelotte Park special map. By comparing the map with the plate the geology of the hill as shown in the picture may be understood. At the left-hand end of the picture there is found a normal contact of Silurian dolomite and Cambrian quartzite, which here strikes east and west and dips north. This contact is not visible on the plate, but is shown on the map. A short distance south of this an east-west fault brings down the dolomite, so that it outcrops to the south of the quartzite again. This dolomite occupies a portion of the left-hand side of the picture, immediately under the pronounced sag in the outline of the hill. A short distance south of this another cross fault brings up the Cambrian quartzite again. This quartzite is seen outcropping in a white streak running down the hill just north of the central part of the picture. Southward again there appear successive faults, belonging to the same east-west system; the first brings up the dolomite shown in the dark area in the very center of the picture; the next fault south brings up the quartzite, and still another has restored the dolomite. This last outcrop of dolomite is seen in the right-hand side of the picture, its lower end being obscured by the intervening spur of Copper Hill. To complicate this numerous system of east-west cross faults, there is a flat, easterly dipping fault, which apparently has a northeast trend, and is a sort of splinter between the Copper and Ontario faults. This flat fault may be noticed in the plate, running nearly horizontal, not far from the top of the hill. It operates so that the middle belt of dolomite is

widened in outcrop, and the belts of quartzites which bound it on each side are thrust away to the right and to the left. There are also numerous minor complications in the structure of this hill, some of which are shown on the map. This is but one illustration of the complicated and puzzling structure found in this district.

Many of the east-west faults are continuous across only one interval between neighboring north-south faults. Others traverse two or three such intervals, while some, as the Butte fault, cross the whole district. This Butte system, therefore, is less persistent than either of the north-south systems which have been described, and the faults belonging to it have usually much less throw than the faults belonging to those systems. Of the faults whose throw can be measured with a degree of certainty, the Butte appears to be the largest, having a downthrow to the north of about 400 feet. The Grand Duke fault, in Tourtelotte Park, near the Butte fault, is estimated to have a downthrow to the north of 200 feet; the Burro fault has a downthrow to the south of about 150 feet; but there are many faults in which the displacement averages less than 100 feet, which may be a downthrow either to the north or to the south.

Age of east-west faults.—The existence of ore in Tourtelotte Park along fractures and small faults belonging to the east-west systems shows that this set of fractures was originated before the ore deposition, probably about the same time as the West Aspen Mountain north-south faults and as the Castle Creek fault itself. As examples of such mineralization, the Good Thunder fault, which carries an important ore shoot, and the "canyon" or shoot in the Justice mine, as well as similar shoots in neighboring mines, may be mentioned. But nearly all the faults of this system which have any important throw are barren, and apparently cut and dispose the ore bodies and the inclosing rocks in the same manner, showing that the chief movement was post mineral. This is also shown by the faulting of the premineral faults, such as the Saddle Rock and the Sarah Jane, as shown on the map; also by the faulting of the Castle Creek fault by the Butte fault.

As to the relative age of the Justice system of north-south faults and the Butte system of east-west faults, it may be noted that the fact that the Butte system does not seem to fault the Justice system would indicate that they are of nearly the same age. It must be borne in mind, however,

VIEW ACROSS QUEENS GULCH TO CASTLE BUTTE.

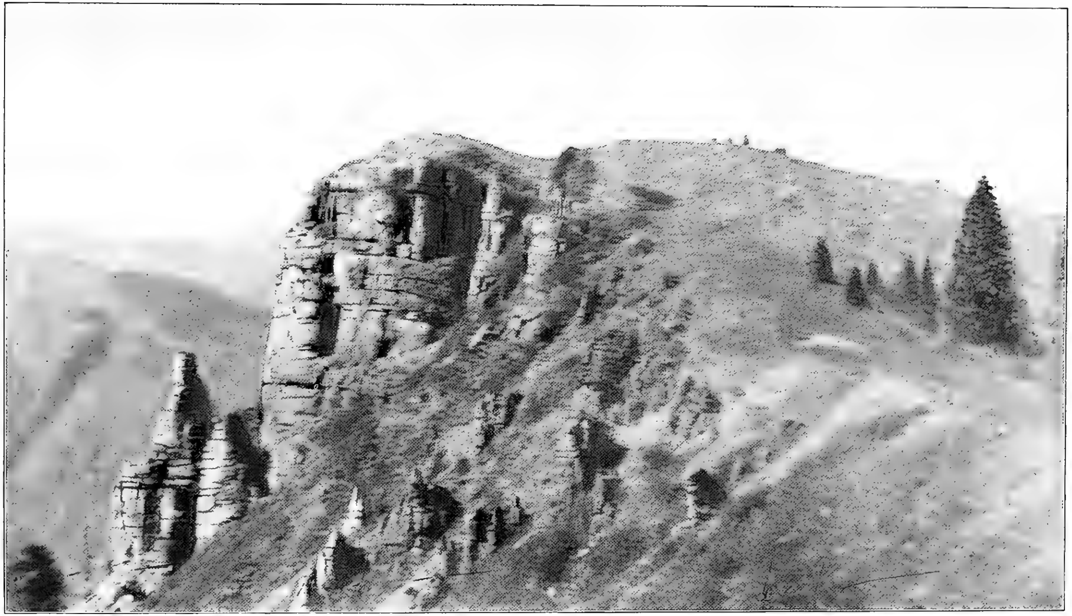
that the movement along these faults was not accomplished suddenly, but has been a gradual process extending over long periods. The evidence is conclusive that this has been the case with many, if not all, of the faults of the Aspen district, and that many of them are even now in process of formation. It is, however, also evident that the maximum amount of movement in some was accomplished at a different time from that in others, and the difference in time of this maximum movement in two systems is taken as their relative age. So, while in the Justice system the movement has occurred mostly since the maximum development of the West Aspen system, yet there is no conclusive evidence of great movement in very recent times. In some of the faults of the Butte system, on the other hand, nearly all of the dislocation has been brought about in very recent times, and there is good evidence to show that in some cases these faults have developed entirely since the Glacial period. The whole of the Aspen district, so far as examined, shows many proofs of extensive glacial erosion, in the accumulation of morainal drift, the transportation of bowlders, and the carving of the bed rock into rounded, fluted, or drumlinoid forms. This glaciation occurred in such relatively recent times that the forms resulting from it are still comparatively unaltered by subaerial erosion. It is this fact which indicates the recent age of the faults.

Perhaps the best example of these post-Glacial faults is the Butte fault, the chief one of the east-west system. On going south on the west side of the Tourtelotte Park basin, along the divide between the basin and the gulches on the west side of the hill, one passes from Weber shales across the Sarah Jane fault to blue limestone, which outcrops on a flat-topped hill. Proceeding along this flat-topped hill, one comes suddenly to an abrupt escarpment or cliff, which is in large part nearly vertical, and has a total height of about 400 feet. This striking topographical form has received the name of Castle Butte.

Pl. V is from a photograph of this cliff, taken from a point across Queens Gulch, at a distance of about a mile, and shows well the bold, abrupt break, and the castellated structure produced by erosion. In detail the butte presents several distinct variations. At the bottom there exists, where not obscured by talus, a strikingly peculiar cliff, probably 150 feet in height, which, in the plate, is shown just to the left of the highest point

of the butte. This cliff is made up entirely of Silurian dolomite. Above it come the sandy and shaly beds of the Parting Quartzite, which have been eroded back so as to form a terrace. Next above is the Leadville dolomite, reaching nearly to the top of the butte, which is of the blue Leadville limestone. As may be seen in the plate, the Carboniferous dolomite shows some evidence of subaerial erosion, presenting a steeply sloping hill which carries some vegetation. The upper rocks are soft and crumbling, and are often weathered into tall pinnacles. This castellated structure is better shown in Pl. VI, which is a view of the butte taken from a point on the scarp a little east of the main development of the cliff. In the foreground the scarp is visible, although somewhat obscured by talus, while in the center of the picture are some of the bold pinnacles and cliffs which have been described. These structures are, of course, due to post-Glacial subaerial erosion. It must be remarked, however, that the effects of such subaerial erosion are much better marked at the top of the cliff than lower down, so that there is a progressive tendency to freshness in the outcropping rocks, and a diminution of the effects of erosion toward the bottom of the cliff. The Parting Quartzite, occurring a little more than halfway down, has been eroded back a few feet, forming a terrace on the top of the Silurian dolomite, but the dolomite itself shows no extensive weathering. The cliff which it forms is strictly perpendicular, having no tendency to crumble or to form a sloping surface. The rock is hard and fresh, well polished along its whole face, and heavily and uniformly striated. From the base of the cliff these striæ can be distinctly seen to extend as high as 75 or 100 feet from the bottom; higher than that they appear to be obliterated. They are plainest and freshest at the base, and grow dimmer progressively toward the top. The line of this cliff is the outcropping of the Butte fault, as is shown by the relations of the strata on both sides. Below the cliff the Parting Quartzite outcrops a considerable distance farther down the hill, showing a downthrow to the south of about 400 feet, which, it may be remarked, is the total height of the escarpment.

The striæ on the polished surface of the dolomite cliff dip 70 degrees to the west on the vertical face of the cliff and indicate by their form an unmistakable downward throw on the south side. It seems clear that this polished surface is the actual plane of movement of the Butte fault, and



CASTLE BUTTE, FROM THE EAST.

that the striæ were formed during the progress of this movement. The question, then, which naturally arises is, Is the fault progressing faster in its upward movement than are the processes of erosion in their degrading action, or has erosion simply acted more vigorously along the fault plane? If the latter is true, it must be that the erosion which has produced this escarpment is post-Glacial, for any glacial action would inevitably have abraded the polished surface and removed all traces of the striæ. Judging from the effects of post-Glacial erosion as exhibited elsewhere in the district, and even in the vicinity of the butte, one must conclude that it has not been nearly so great in amount as to be able to accomplish such a work; and even if such an amount of work were possible the same objection holds good as in the case of glacial erosion, namely, that during the other processes of degradation the striæ along the fault plane must have been obliterated.

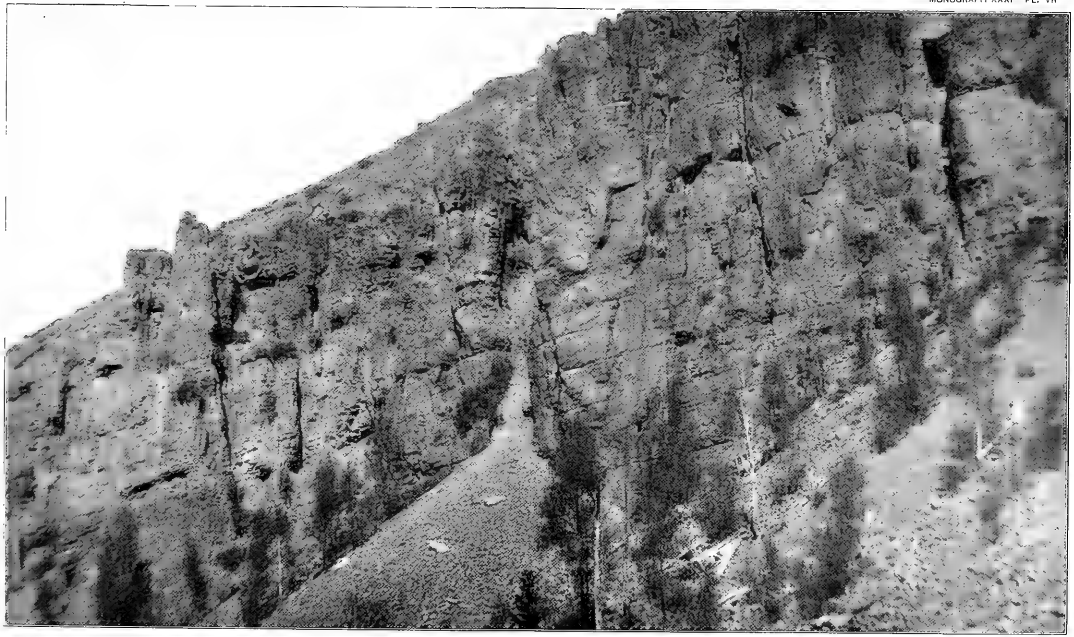
The talus at the foot of the cliff was examined to see what might be its main source, and it was found to consist almost entirely of fragments derived from the Parting Quartzite or from the overlying Carboniferous rocks. The distinction in lithological character between the dolomite of the Silurian and that of the Carboniferous is usually slight, but in Castle Butte there seems to be a distinction in texture by which the two rocks may be separately recognized; and judging from this, there appears to be in the talus very little material derived from the Silurian.

On both sides of the fault at this point are rocks which have about the same degree of resistance to erosion, for opposite the Silurian dolomite in the cliff there lies the corresponding dolomite of the Carboniferous. There is therefore no apparent reason why erosion should have attacked the rocks to the south of the fault more vigorously than to the north. Moreover, the peculiar freshness of the striæ at the bottom of the cliff and the progressive effacing of these marks toward the top, together with the fact that the amount of erosion becomes progressively greater and greater to the very top of the butte, is evidence that the erosive forces have acted longest at the top of the escarpment and practically not at all for a distance of 75 or 100 feet from the bottom; and even at the top the amount of erosion has been comparatively slight. The only explanation of this seems to be that the scarp actually represents the entire amount of throw of the Castle Butte fault, and that this fault has come about almost entirely since Glacial time.

Pl. VII gives a view of the perpendicular cliff of jointed Silurian dolomite, with its polished and striated face.

Another fault, which appears to be post-Glacial and which belongs to the same system, is the Burro. Where this fault crosses the ridge to the west of Spar Gulch there is a marked north-facing escarpment, approximately 150 feet high, which is about the actual throw of the rocks at this point. Pl. VIII is a view taken from the west side of Castle Creek fault, looking eastward across the intervening valley. The escarpment is seen at the top of the picture against the horizon. If this is imagined to be removed and the right half of the hill depressed to a level with the left half, it will be seen that the hill has the lenticular, drumlinoid outline which is so characteristic of glaciated surfaces. There can be little doubt that this was the actual form in which it was left by the overriding glaciers. The preservation of this smooth outline to the present day shows that there has been no great amount of post-Glacial erosion; and since the amount by which this typical drumlinoid outline has been displaced is exactly equal in amount and direction to the displacement of the underlying rocks by the Burro fault, it seems highly probable that the whole movement has come about in post-Glacial times. The rocks which now outcrop on the hill are, on the right side of the escarpment, porphyry, and on the left the blue Weber limestones which underlie the porphyry.

The Butte and Burro faults are probably the most interesting and conclusive proofs of the recent age of some faults of the east-west system. There is, however, considerable additional evidence in various places to show that the movements along many of these faults are still going on, and some of them are probably attaining their maximum development at the present time. Along many of the faults in Tourtelotte Park there are scarps, but it must be borne in mind that such a scarp is not necessarily one of uplift, but may be a scarp of erosion. Such an erosion scarp may occur along a fault which has not had great development since Glacial times, and may result from the rapid wearing away of soft beds on one side of the fault as compared with the slower degradation of the harder beds on the other. In Pl. IX is shown such an erosion scarp, which was formed in Glacial time. This is along the Sarah Jane fault. The plate looks to the northwest. On the right side the surface is underlain by the soft shales of the Weber, while on the hill to the left the blue Leadville



FAULT SCARP ON FACE OF CASTLE BUTTE.

limestone crops out, and the fault runs along the base of the scarp. In such a case as this, where the dislocation was accomplished mainly in pre-Glacial time, the erosive action of the glacier must have scooped out more of the soft shale than of the harder rock, and thus produced the scarp. It is to this differential glacial erosion that the formation of the entire hollow basin called Tourtelotte Park is due.

As a general distinction between scarps of erosion and those of uplift in this region, it may be remembered that erosion scarps are likely to occur where there is considerable difference in hardness of the rocks on the two sides of the fault, and that in this case the scarp will probably be sloping. The uplift scarp, however, may originate perfectly well where the rocks have the same hardness on both sides, and such a scarp may have an almost perpendicular face. Faults undoubtedly exist where the movement was begun in pre-Glacial times, and still continues slowly, so that part of the movement is pre-Glacial and part post-Glacial; and along these may be formed scarps partly of erosion and partly of uplift. Pl. X shows the scarp of the Silver Bell fault, which is perhaps an illustration of this. The hill shown on the right side of the picture is made up of the hard limestones and dolomites of the Leadville formation, while the flat surface shown in the foreground is underlain by the soft black Weber shales. At the base of the hill is the fault, along which there is a zone where the dolomite is altered and silicified, so that it forms a sort of chert, which may be called *jasperoid*. The main scarp is undoubtedly due in this case to glacial erosion, but it is possible that a few feet of the cliff at the bottom, which may be found where not obscured by talus from the hill above, may be due to uplift since the Glacial period. This cliff is nowhere very strikingly developed, and in this picture can be seen only just to the right of the gallows frame in the center.

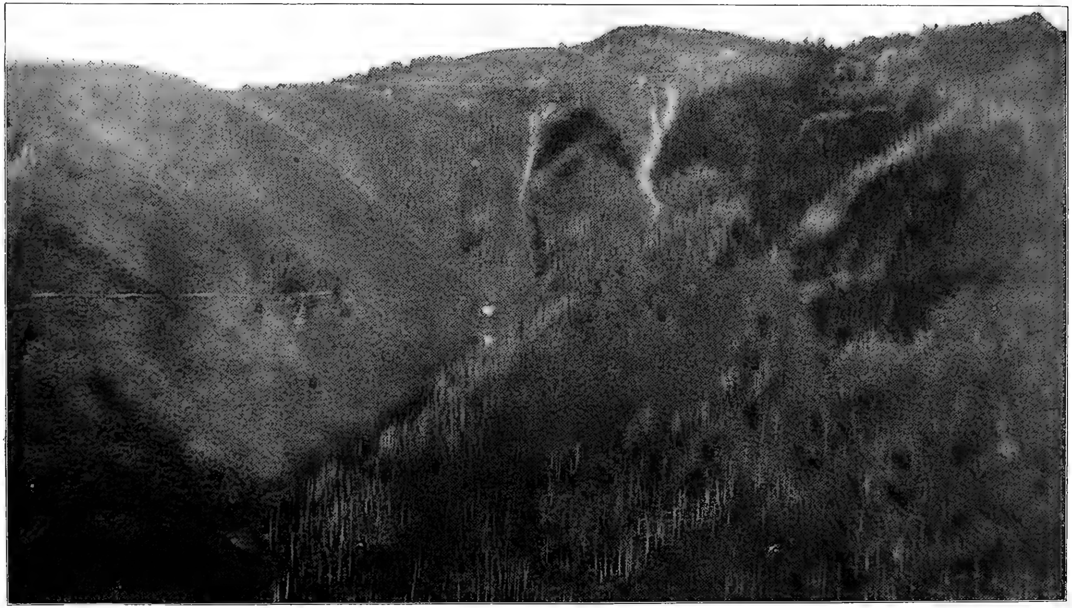
RÉSUMÉ OF STRUCTURE IN THE AREA OF THE TOURTELOTTE PARK SPECIAL MAP.

The various mechanical accidents which have happened to the rocks in the Tourtelotte Park district since their formation, bringing about changes from their original position, may be enumerated as follows:

1. The first deformation.—The first deformation consisted in a folding of the sedimentary beds against the hard resisting granite axis of the Sawatch.

The folding had its maximum development in a line running approximately parallel with this granite axis, and the movement was especially important in the upper beds, resulting in an overthrown, easterly dipping syncline, which had a slight pitch to the north. Judging, however, from the nature of this folding in the lower rocks, as now exposed by erosion in the southern part of the Tourtelotte Park special area, the amount of deformation is there not nearly so great; and it is probable that the fold became progressively less with depth and disappeared entirely in the granite. It has already been noted that with the increase in depth the overthrown, eastwardly dipping syncline tends to straighten up, and finally resolves itself into a normal open fold. To the west of this chief axis of folding there is a series of open folds, which, however, die away in a short distance, so that the beds become comparatively undisturbed. To the east of this main axis, and between it and the granite, there existed a series of open folds, such as are now exposed by erosion in the Tourtelotte Park district, which were probably heavy in the upper strata, but all very gentle in the lower beds.

2. The Silver system of faults.—Synchronously with the folding, and as a result of it, there was a certain amount of slipping of one bed over another to accommodate themselves to the new position into which they were forced. This gave rise to fault zones or fault planes nearly or quite coincident with the bedding, which, however, have great persistence and a notable amount of displacement, and have played an important part in the economic history of the region. These faults are very numerous throughout the whole district, but two of them are perhaps more important in the study of ore deposition than any two other faults which may be found. One of these, which has been called the Contact fault, appears to be strictly parallel with the bedding, at the contact between the blue foraminiferal limestone and the underlying dolomite of the Leadville formation. Its displacement, therefore, can not be measured, but that it has been considerable is proved by the slickensiding and brecciation almost always found along it. The other fault is also very nearly parallel to the bedding, but frequently cuts it at a very slight angle, so that portions of the strata are carried away by its action in certain localities. The amount to which the strata have thus locally been cut down shows that the movement along the fault has been very great.



VIEW ACROSS CASTLE CREEK UP OPHIR GULCH, SHOWING BURRO FAULT SCARP.

3. The first system of north-south faults.—The overthrust fold described above culminated in a great fault along its axis, called the Castle Creek fault. This fault varied in magnitude, as did the preexisting fold, being greatest in the upper beds, diminishing in the lower, and probably dying out in the granite. With depth, also, the easterly dip steepened, and finally, as shown in the southern part of the Tourtelotte Park special map (Atlas Sheet XII), became practically vertical. Probably at about the same time with the Castle Creek fault other parallel displacements occurred, the greatest naturally being close to the master fault. The most notable are the north-south faults of West Aspen Mountain, which have a heavy throw, while the parallel breaks farther to the east have progressively slighter displacement. There was also developed, probably at about this time, a series of cross fractures, running east and west between the main north-south faults, but the rocks do not seem to have had any great movement along these east-west planes till a later date.

The movements which have been thus summarized, together with some complications which need not be mentioned here, all occurred previous to the deposition of ore, as is shown by the fact that ore solutions have chosen them by preference as loci for the mineralization. They may be conveniently separated from the succeeding movements which are about to be enumerated, and which took place subsequent to the deposition of the ore, and may be classified as premineral, while the later movements are postmineral.

4. Postmineral movement.—Subsequent to the period of ore deposition there was a movement along certain north-south fractures which had originated, probably, at the same time as the north-south faults on West Aspen Mountain. This postmineral movement produced, chiefly, the Tourtelotte Park north-south fault system, of which the Justice, the Copper, and the Ontario faults are examples.

5. Post-Glacial movement.—A continuation of the movement made itself manifest in the east-west fractures, which also probably originated at an early date, but did not attain any great importance until this later period. This movement, a large part of which was brought about in post-Glacial time, gives rise to the system of east-west faults, of which there are numerous examples in the northern half of the Tourtelotte Park special area.

DESCRIPTION OF SECTIONS.

On account of the extremely complicated structure in the Tourtelotte Park area, it was necessary to construct many sections in order that the geology might be made reasonably clear. (See Atlas Sheets XIII, XIV, XV.) Inasmuch as the axis of the main fold runs parallel to the main ridge in Tourtelotte Park, cross sections were constructed at right angles to this ridge, and six east-west sections were finally selected for publication. Another series of sections was constructed at right angles to the others. Thus the two sets form a sort of rectangular grating, as shown on the map (Atlas Sheet XII), and by taking the east-west sections together with the north-south ones a comparatively clear idea of the structure of the district may be obtained. All the east-west sections look toward the north, and all the north-south sections toward the east, a system which has been adopted throughout this report.

Section A.—At the western end of the section the Maroon beds are overturned at the surface, while with depth the return of the strata to their normal succession is seen. The overthrown fold rests against the Castle Creek fault, and the curved form of this fault, which has been inferred from its change of dip toward the south, is shown in the section. On the east side of the fault is the Archean granite, showing how great the throw has been at this point. Toward the east granite outcrops in the section continuously nearly to the Saddle Rock fault. Just west of this fault, however, there comes in, probably in its normal succession above the granite, the Cambrian quartzite, which contains in its lower part a thin sheet of diorite. These beds dip to the east, forming a part of the west limb of the Aspen Mountain syncline, and they are successively downfaulted to the east by the Saddle Rock and the Sarah Jane faults. These two faults are shown in the section as cut and displaced by a lower fault. This belongs to the east-west system, but on account of its dip cuts the plane of the section in somewhat the manner represented.[1] This east-west fault has a slight downthrow to the south, and is called the Dixon fault, from its being best shown in the mine of that name. East of the Dixon fault is shown a very shallow syncline, the axis of which lies nearly under the ridge of the hill. This

[1] In studying the sections care should be taken to remember that the angle of the faults as plotted is not always the actual dip, for the angle represented is that which the fault plane makes with the plane of the section. Thus a fault which has a dip of 70 or 80 degrees may appear as a horizontal line in a section parallel to its trend.

SARAH JANE FAULT SCARP

syncline is unbroken as far as Spar Gulch, where the Justice fault is encountered, which has a considerable downthrow to the east. East of the Justice fault the beds dip at an angle equal to the slope of the hill, and so present their basset edges in outcrop on the eastern side of the hill in Copper Gulch. In the bottom of Copper Gulch the Copper fault is encountered, which has a slight downthrow to the east. This is, however, abnormal, being caused by the later movement of the minor east-west faults which have introduced much complexity in the structure of this locality.

East of the Copper fault is a flat, easterly dipping fault, which forms, apparently, a sort of splinter between the Ontario and Copper faults, and which has probably no great persistence, as it certainly has no great throw.

In the strata between the Ontario and the Copper faults appears the axis of the anticline which joins the Aspen Mountain syncline on the west, and which is indicated on East Aspen Mountain and is present in a large part of Tourtelotte Park. This tendency toward the assumption of a flat position, or even of a slight anticlinal structure, is also found in the Hunter Park and Lenado districts. In Lenado Canyon a slight anticline, resting against the granite, is fully exposed on a vertical cliff a short distance above the village, and the same structure, dying out toward the south, can be traced over a large part of the Hunter Park map.

The Ontario fault, in this section, has a comparatively slight downthrow to the east, but the next fault to the east probably belongs to the same system, and it may well be that the two have split off from the main Ontario fault, which was traced farther to the south. In the block to the east of the fault last mentioned, which may be called Ontario No. 2, the beds have a position which indicates a slight syncline, resting against granite. The tendency toward this final synclinal structure is also shown in parallel sections farther south. The last fault shown on the map as existing in the granite is the continuation of a fault of the east-west system.

Section B.—In Section B there is shown on the west, as before, the Castle Creek fault, and the steeply dipping beds which lie against it. In this case, however, the overthrown beds resume their normal position at a much less distance from the surface than in Section A. There are also shown two minor faults to the west of the Castle Creek fault, which are nearly parallel to the main fault, and divide the total throw, there being a continuous upfaulting to the east along each plane. The actual number of these slip

planes is very great and can not be precisely ascertained, but on some of them the movement has been much greater than on others, and along such planes it has been found advisable to represent the total movement as having occurred. The two faults shown in the section have actually been traced over nearly the whole southern part of the area of the Tourtelotte Park special map (Atlas Sheet XII). The western one may be called the Annie fault, and the eastern one the Dubuque fault, from their being best shown, respectively, in these mines. Faults of this character may be called dependent faults, since they are really parts of the main or master fault, which in this case is the Castle Creek. Owing partly to the action of these dependent faults, and partly to the change in attitude of the beds on the west side—partly, also, to the somewhat lower position of the rocks on the east side—the entire throw of the Castle Creek fault has considerably diminished from that shown in Section A.

East from the Castle Creek fault the Cambrian quartzite is soon encountered above the granite. This is in turn overlain by the Silurian dolomite, which extends as far as the Saddle Rock fault. This fault has its usual downthrow to the east, and places the outcrop of the Carboniferous dolomite adjacent to that of the Silurian. Farther up the hill comes the Silver fault, with the thin strip of crushed shale which separates the Leadville limestone from the main sheet of porphyry. Close to this point the Sarah Jane fault is encountered, with its usual downthrow to the east. East of this fault is shown the remnant of the Aspen Mountain syncline, in a position corresponding to that in Section A. This is practically continuous and unbroken as far as the Justice fault. Between the Justice and the Sarah Jane faults is a slight displacement, arising from the Good Thunder fault. This fault belongs to the east-west system, but, on account of an irregular crumpling in this plane, actually cuts the section as represented. In the 300-foot section (see Section F, Atlas Sheet XXIII), along this same line, the fault is more accurately represented as intersecting the plane of the section in two lines, but in the 800-foot section the intersection has been represented, for the sake of simplicity, as in a single line. The Justice fault has its usual downthrow to the east and is cut at the place where its throw has been best measured. Immediately east of the Justice fault the main sheet of porphyry cuts up across the bedding of the Weber shales, leaving a considerably increased thickness of

SILVER BELL FAULT SCARP.

shale between it and the limestone. Farther east come in two faults of the east-west system, which, on account of the angle of intersection which their planes make with the plane of the cross section, seem to have a flat dip to the west. Their actual dips, however, are nearly vertical, as can be seen on some of the north-south sections, which cut their planes more nearly at right angles. East of these faults the Parting Quartzite crops at the top of the hill. In the gulch on the east side of the hill runs the Copper fault, having here its normal upthrow to the east. At about this point the Aspen Mountain syncline flattens, preparatory to forming the adjacent anticline, and so the outcropping beds pass into the air, giving place to granite farther down the hill. The throw of the Ontario fault, however, brings down the rocks so that the Silurian dolomite on the east abuts against the granite on the west. Below the Silurian dolomite the Cambrian quartzite and the granite are again exposed. The last fault shown in the section belongs to the east-west system.

In the block which lies between the Ontario fault and this east-west fault last mentioned is a little synclinal basin, which dips in on all sides toward the center.

In this section the thin diorite sheet is somewhat higher up in the Cambrian quartzite than in Section A. This sheet also thins out and disappears toward the west, so that where the quartzite outcrops on the western slope of the hill no diorite is found.

Section C.—West of Castle Creek fault in this section the Maroon and underlying formations are slightly overturned at their outcrop, but right themselves almost immediately below the surface, and assume their normal succession. In this section the Weber formation comes in definitely and persistently in its normal place below the Maroon formation. East of the fault the Silurian dolomite outcrops. The dependent faults west of the Castle Creek drag up wedges of the underlying formations, so that the Leadville limestone nearly reaches the surface at the outcrop of the main fault. The throw of the fault is thus greatly diminished, although still large.

East of the Castle Creek fault the Saddle Rock fault comes in, having its usual downthrow to the east. The next break is the Sarah Jane, which has at this point a considerable downthrow to the east, and the next is the Justice, whose movement is a downthrow to the west, the reverse of

the usual displacement. The increased throw of the Sarah Jane and the apparent reversed movement of the Justice are, as before explained, due to the downfaulting of the wedge included between these two faults near their intersection. The first fault east of the Justice is apparently slight, and is probably a nonpersistent cross fault, having a northwest trend. It is marked in the topography by a continuous scarp, and seems to have a slight downthrow to the northeast, as represented.

East of this fault the continued westerly dip brings the Silurian limestone into outcrop. On the eastern slope of the hill the Copper fault is encountered in its usual position, with its maximum development. Its movement is an upthrow to the east, so that the Cambrian quarzite rests against the Silurian dolomite. Below the quartzite granite outcrops along the section plane till the east-west Butte fault is obliquely intersected. On the south side of this fault come again the Silurian dolomite and Cambrian quartzite, which in turn give way to the granite

In this section the only shale is that in the little downthrust block between the Justice and the Sarah Jane faults, and there is no porphyry whatever. This is due to the northerly pitch of the beds, which carries the strata successively above the surface toward the south. The diorite sheet has in this section taken up its place in the middle or near the upper part of the Silurian dolomite, having cut up across the strata in the distance intervening between this section and Section B.

Section D.—West of the Castle Creek fault in this section the beds change at their point of outcrop from their reversed easterly dip to their normal westerly one. East of the fault the Cambrian quartzite and the lowest part of the Silurian dolomite outcrop. The next fault encountered runs north and south, and is probably the Saddle Rock. This has a slight downthrow to the east.

The first of a series of east-west trending faults, which have a dip toward the south, is next cut. On account of their dip, these faults cut the plane of the section in nearly horizontal lines, as represented. The fact that both the east-west and the north-south faults cut the same section explains the somewhat complicated structure here shown. The Justice fault, which, after uniting with the Sarah Jane, probably dies out against one of these east-west faults, outcrops at this point a little to the north of the line of the section, and does not, therefore, cut this section plane at the surface;

but since the fault against which it is represented as stopping has a southerly dip, this fault and the Justice fault with it enter the section at some distance below, as represented, and continue indefinitely downward.

The general structure is that of a westerly dipping monocline, with some slight trace of the gentle foldings which were observed in the section farther north on the east side of the hill. The granite outcrops in its natural position below the quartzite until cut off by the Ontario fault, which has its normal downthrow to the east, and brings the bottom of the Silurian dolomite against the granite. The beds at this point lie nearly flat, and possibly have a very slight westerly dip, so that on going down the hill the edges of the dolomite and underlying quartzite are passed over to the granite. In this section the diorite sheet is thicker than in the sections farther north, and lies only a short distance below the Parting Quartzite.

Section E.—West of the Castle Creek fault the beds have in this section definitely resumed their normal position, and dip steeply to the west. East of the Maroon formation nearly the whole Weber formation outcrops, and it is probable that below this line porphyry, blue limestone, and the rest of the usual succession occur.

East of the fault there lies, as in the preceding section, the Cambrian quartzite, which has a gentle westerly dip. This dip being considerably less than the slope of the hill, the Silurian dolomite comes in above the quartzite a short distance up. The first fault encountered runs north and south and has a slight downthrow to the east. This is probably the Saddle Rock fault. East of the Saddle Rock fault there intersect the plane of the section a number of the southerly dipping east-west faults which have been previously mentioned, and which, on account of their trend being nearly parallel with the trend of the section, intersect the section plane in a nearly horizontal line.

As in the previous section, the general structure is that of the westerly dipping monocline, with some slight indication of a tendency toward the old anticlinal structure near the top of the hill. Where the strata successively outcrop on the west side of the hill, however, they have still a slight westerly dip. Granite outcrops a short distance down the hill, as far as the Ontario fault, when the downthrow of this fault brings in the Silurian dolomite to the east. Passing down the hill, however, one goes across the edge of the Cambian quartzite to granite, which continues to the end of the section.

In this section the diorite is slightly higher in position than in any of those farther north. It has attained about the horizon of the Parting Quartzite, which it frequently cuts across, and small bodies of which it sometimes surrounds. Its thickness is probably about the same as that of the Parting Quartzite itself.

Section F.—In this section the beds west of the Castle Creek fault are seen more fully restored to their normal succession. The chief dependent faults—the Annie and the Dubuque—both outcrop. The convergence toward the south between the trend of the Castle Creek fault and the line of contact between the granite and the overlying sedimentary beds has so reduced the distance between the Castle Creek fault and the granite in this section that it is very slight. The northerly pitch of the beds, moreover, has brought to the surface successively lower and lower formations, so that in this section the highest horizon east of the Castle Creek fault is that of the Parting Quartzite. The Parting Quartzite, however, is not represented in the section, for the diorite sheet, here apparently as much as 100 feet thick, has superseded and traversed the Parting Quartzite until the exact position of the latter is not recognizable. Thus the place of the Parting Quartzite is occupied by the diorite, and above the diorite the Leadville formation comes in. Below the Silurian dolomite on the east side of the hill the Cambrian quartzite is continuous to the Ontario fault. This fault brings down into the section the very bottom of the Silurian dolomite, which passes immediately across the Cambrian quartzite into the granite. The fault represented just below the contact of the Cambrian quartzite with the granite is a nonpersistent north-south fault, which has some slight upthrow to the east. The last fault shown in the section as outcropping in the granite on the side of the hill is one of the series of east-west southerly dipping faults.

Sections G, H, and I (Atlas Sheet XV) are north-south sections, running at right angles to the six sections which have already been described.

Section G.—This section starts in granite on the slope of East Aspen Mountain, just above Roaring Fork Valley, and at a little distance south it runs into the north-pitching series of sedimentary beds. The pitch of these beds tends to carry them into the air, but they are continually thrust down toward the south by parallel east-west faults. These faults are shown in the section as reversed, and from all the information that could

VIEW FROM LENADO, LOOKING EAST UP THE CANYON.

be obtained they are actually so, but it is possible that additional information might prove them to be otherwise.

In the most important of these downthrust blocks appears the peculiar local syncline described in Section B. If the two are taken together it is seen that the beds form a true synclinal basin, in which the strata dip on all sides toward a common point. Between the southern end of this synclinal basin, where it is cut off by an east-west fault, and the corresponding sedimentary beds on the south side of the Butte fault, there intervenes the upthrust block which has already been referred to as having apparently not been affected by the movement of the Ontario fault. In this block, therefore, only granite comes into the section. South of the Butte fault the section runs into the Cambrian quartzite again, and so continues nearly to the end, since the strike of the beds is nearly parallel with the section. This continuity is interrupted in occasional blocks, which are shifted from their normal position by movement along east-west faults, and toward the southern part of the section a slight deviation between the strike of the beds and the line of the section brings in the bottom of the Silurian dolomite. Between this point and the southern edge of the area mapped the section encounters three parallel east-west faults, all of which have a uniform upthrow to the south; and as their dip seems to be in a southerly direction, they are apparently reversed. These faults bring in the granite.

Section H.—Section H runs along the ridge of the hill through a region of great disturbance. In the northern half of the section there is a general northerly pitch of the beds. The rocks are disturbed by many east-west faults, which have apparently no uniform movement, so that it appears as if the rocks had been divided by these parallel faults into blocks, which have moved irregularly one upon the other.

The Copper fault, which belongs to the north-south system, has a westerly dip, which carries it into the section. Many of the east-west faults which lie to the east stop on reaching this fault, while many on the west side are also nonpersistent and stop at this plane. This explains the presentation of the faults in the section. Those which are drawn below the Copper fault and which stop on reaching it represent faults in the eastern block, while those which crop at the surface and stop in their downward course on reaching the Copper fault are the nonpersistent faults which lie in the western block. There are, however, certain ones which

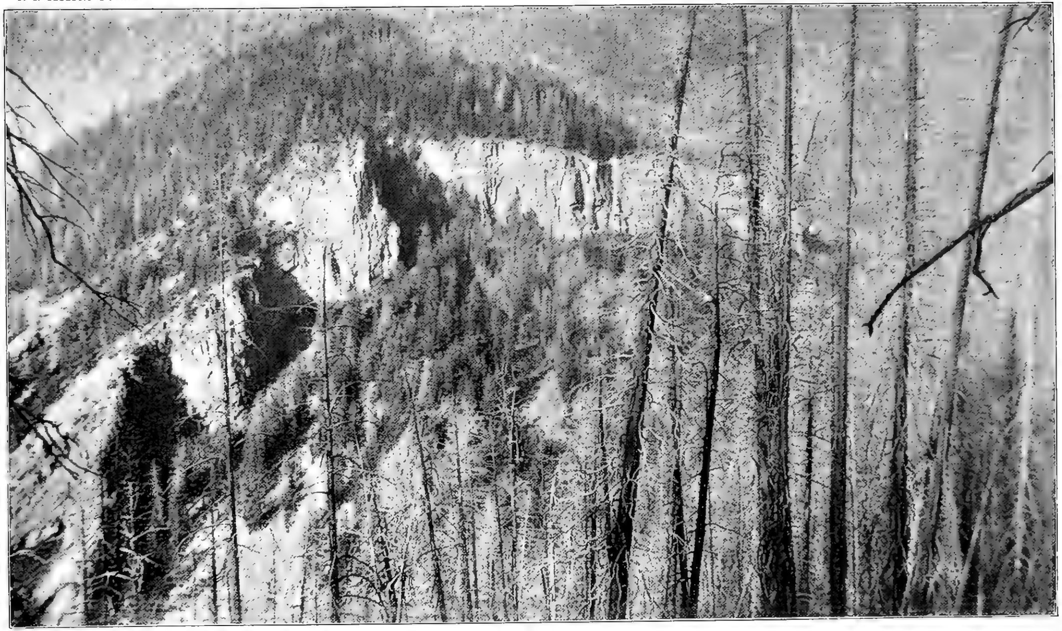
run from top to bottom of the section, and these are the faults which run across both blocks, traversing the Copper fault without any apparent break. This section illustrates well the great difference in persistence of these east-west cross breaks.

The Butte fault has a slight downthrow to the south, and south of this are a great number of parallel east-west southerly dipping faults. The beds along the top of the hill have a slight northerly pitch, so that lower beds tend to outcrop successively toward the south; but these parallel faults have a uniform slight downthrow to the south, so that the outcropping horizon, which is about at the Parting Quartzite, is kept very nearly the same. The southernmost of these faults, however, appears to differ from the rest in having a reversed upthrow to the south.

In this section the change of position in the diorite, as illustrated from place to place in the east-west sections, may be continually followed. At the southern end of the section the diorite occupies the position of the Parting Quartzite, between the Silurian dolomite and that of the Carboniferous, and it appears here in its maximum thickness, so far as the present mapping goes. Toward the north it cuts very gradually down across the beds until about the center of the section, where it cuts down more rapidly and enters the Cambrian quartzite. In this it continues, gradually getting deeper, as far as the northern limit of the mapped area, where it is a very thin sheet, lying close to the granite. A short distance farther north, on Aspen Mountain, the diorite disappears.

Section I.—In this section granite outcrops at the north end. Farther south is a series of faults which belong to the east-west system, and which have the effect of thrusting down the blocks to the north.

Between this faulted area and the place where the section cuts the Castle Creek fault there is a comparatively undisturbed portion, in which the beds lie nearly flat, with only slight undulations along the strike. Thus the Cambrian quartzite is exposed in outcrop, with the Silurian dolomite overlying it, on the ridge cut by the section. The Castle Creek fault is cut obliquely, as well as the two main dependent faults, the Annie and the Dubuque. The east-west fault, which has been called the Butte, has cut and faulted the Castle Creek fault, being of later origin; and as the section cuts the formations near the intersection of all these faults, the structure shown is complicated.



FOLD IN CAMBRIAN QUARTZITE ON THE NORTH SIDE OF LENADO CANYON.

South of the Castle Creek fault the section does not encounter any disturbance, but cuts the steeply dipping sandstones and shales in a nearly horizontal zone.

RÉSUMÉ OF FAULTING.

In the six east-west sections which have been described the north-south faults have a general downthrust to the east. This is comparatively uniform. The throw of the east-west faults, however, as seen in the three longitudinal sections, G, H, and I (Atlas Sheet XV), is not nearly so uniform. In Section G the east-west faults to the north of the Butte fault have a general downthrust to the south, while in the same section the common throw of the same system of faults to the south of the Butte fault has been up to the south. In the northern part of Section H there is a general downthrow to the south; in the central part there is no uniform direction of throw, the blocks having moved up and down indiscriminately; in the southern part there is a tendency toward a downthrust to the south. In Section I the common throw of the faults in the northern part of the section seems to be down to the north. So the total effect of all the faulting in the Tourtelotte Park area may be summarized as a general downthrow to the south and east, the downthrow to the east being strongly marked, while that to the south is not so uniform.

LENADO SPECIAL MAP.

FOLDING.

The only noteworthy feature in the flexure in the beds at Lenado is a slight anticlinal dome on the extreme eastern edge of the area of the special map, where the lowest beds of the sedimentary series abut against the granite. The fold is best seen in the bed of Woody Creek, about three-quarters of a mile above the little camp of Lenado. At this point the stream emerges from its granite bed and crosses over the upturned edges of the overlying sedimentary formations. This change from the Archean to the overlying rocks is marked by a very striking gap, which is shown in Pl. XI. This view looks east up the valley of Woody Creek from Lenado. The distance between the houses in the foreground and the cliffs which rise above the canyon on both sides is about half a mile. The top of the steep cliff at the right is of Cambrian quartzite, and the quartzite also

outcrops at about the same elevation on the other side, which is also very steep, but is not well shown in the picture. Overlying the quartzite at the extreme left of the plate are the lowest beds of the Silurian dolomite, while underlying the quartzite and forming the base of both of the cliffs is granite. The main dip of the beds is not seen in this picture, being directly toward the observer, but the minor dips to the north and south can be made out in the cliffs on both sides. The top of the cliff at the right shows an outline against the sky corresponding with the attitude of its strata for a short distance north of its brow to the bottom of the little sag. Through this sag runs a heavy fault, to the south of which lies the granite, so that at the extreme right of the picture the outline of the hill has no reference to any stratification.

The cliffs on the left side of this picture are better shown in Pl. XII, which is from a photograph taken from the hill on the south side, looking north across the canyon to the nearly vertical wall. On the extreme left of this picture is the same locality as the left side of the preceding plate, but the two pictures are, as explained, taken at right angles to each other. The abrupt cliff is made up of Cambrian quartzite, and the height of the cliff is very nearly the entire thickness of the formation. The changes of dip in these rocks may be well observed, and bring out the slight anticlinal structure, for this is a natural cross section at right angles to the axis of greatest folding. In the central part of the picture the cliffs are nearly horizontal, as viewed in this east-west section, while to the west the dip grows steeper, until near the bottom it is 35 or 40 degrees. To the east, on the other hand, the beds assume a very gentle easterly dip as far as the gulch which may be dimly seen through the trees at the right in Pl. XII. At this gulch the beds are cut out by the heavy fault before referred to, so that they abut directly against granite. Below the quartzite cliffs the rock is granite, while above them comes in the Silurian dolomite.

The folding in the remainder of the area of the Lenado map is simple, and even monotonous, there being a continuous westerly dip from the western side of the slight anticline above described. Near the eastern end of the area the dip is flatter than farther west, the average at first being perhaps 30 degrees. This dip flattens on the tops of hills and steepens in the valleys, showing the persistence in the curving of the beds conformable with the folding shown in the Cambrian quartzite in Pl. XI.

SILVER CREEK VALLEY, ERODED IN WEBER SHALES.

Farther west the dip steepens gradually, until, at the western end of the section, it averages perhaps 45 or 50 degrees.

Along the valley of Woody Creek the rock exposures are almost continuous, so that a complete section is obtained. After passing westward through the canyon above described, there are successively encountered the Silurian dolomite, the Parting Quartzite, the Carboniferous dolomite, and the overlying Weber shales. Above these come the Maroon beds, with their basal gray limestone. These Maroon beds run continuously in the bottom of Woody Creek as far as the limit of the area mapped, but at some little distance west the line of division between the Triassic and the Carboniferous has been placed, and the strike of this contact just carries it across the top of the hill in the extreme northwestern end of the area.

The successive formations over which the creek passes in its westerly course give rise each to different variations in the shape of the valley. Above the Archean gateway which has been described the valley broadens out, being flanked on either side by steep granite hills which have been worn down from their original shape by the action of glaciers. The sharpness of the canyon across the anticlinal fold is apparently due not so much to the nature of the rocks as to the presence of the fold. The center of the dome, which has a steep dip to the west and a gentle dip to the north, the south, and the east, has been eroded with comparative ease, while the rocks on its sides have been more resistant. Just west of this canyon erosion has gone on with much greater rapidity, so that the widening out of the valley is very striking. The side gulches which run into the main creek now have a considerable length and a comparatively low gradient. This is seen in Pl. XIII, from a photograph taken from Woody Creek looking up Silver Creek, which is one of the side gulches referred to. This gulch has been eroded in the Weber shales, about midway between the contact with the Maroon on the west and the contact of the Leadville dolomite on the east. The Maroon beds come in at the extreme left of the picture. After passing through the Weber formation and entering the red sandstones of the Maroon, followed by similar but probably Triassic rocks, the valley of Woody Creek assumes again a new form, which is continuous throughout a large part of its course, until it passes beyond the sandstones. This part of the valley is in general V-shaped, the hills on both sides having a steep but uniform slope, and the side gulches being short, with steep

gradient. The hills on both sides of this valley are largely bare of vegetation, so that the outcropping strata of red or brown sandstone give a characteristic hue to the landscape, which can be seen at great distances.

Pl. XIV is a view of the northern side of this Lenado Valley in the sandstone district. It is taken from the top of the hill on the south side of the valley, at a point about 1,500 feet above the creek, and looks across the valley and up one of the side gulches. On the left of this side gulch are the perfectly bare outcrops of westerly dipping strata of Maroon sandstone. This type of valley continues until the stream emerges from the red sandstones into the comparatively flat and much softer Cretaceous rocks. Where the stream flows through these, as it does for several miles above its junction with Roaring Fork, the rocks have been worn down to nearly the level of the stream bed itself, so that there is no very deep valley.

FAULTS.

Silver fault.—The contact between the Weber shales and the Leadville dolomite is, throughout the whole of the area shown on this map, apparently a true fault contact, for it is characterized by a brecciated zone and by evidences of slipping in the formation of polished and striated surfaces and in little slip faults parallel to the main contact. These features are, of course, best exposed in underground workings, and are especially well shown in the Clark tunnel and in the Bimetallic tunnel. As far as the evidence on this map alone goes, the fault seems to be strictly parallel to the bedding. In all places the formation lying above the fault is the Weber, and that below is Leadville dolomite. There is not found in this area, so far as observed, any of the blue foraminiferal limestone which lies above the dolomite at the top of the Leadville formation on Aspen Mountain and in Tourtelotte Park.

There may be made three suppositions to account for its absence: (1) That the blue limestone referred to was a local deposit, which was not formed at all in this region; (2) that the limestone was deposited over this area originally as over the area farther south, but that during the erosion interval between the Leadville and the Weber formations the blue limestone, and probably a part of the underlying dolomite, were worn away, so that the Weber shales were deposited directly upon the dolomite; (3) that both the dolomite and the blue limestone existed in this district up to the time

MAROON SANDSTONES ON NORTH SIDE OF WOODY CREEK VALLEY.

of the folding and the formation of the Silver fault, and that the movement of that fault resulted in cutting off the blue limestone and a portion of the dolomite.

The first of these suppositions appears impossible, for the thickness of the blue limestone on Aspen Mountain and in Tourtelotte Park is from 100 to 150 feet, and this formation is known to extend a long distance to the south of this point. North from Aspen Mountain, however, the blue limestone disappears in the bottom of the valley between Aspen and Smuggler mountains, and is not found at any point north of the Roaring Fork in the area examined. It is not probable that a formation having the considerable thickness above referred to should naturally die out in such a short lateral distance. The second supposition has more evidence in its favor, for there is known to have been an important upheaval and erosion interval between the deposition of the Leadville limestone and that of the Weber shales. During this interval the beds must have been in many places eroded, and it is not unlikely that in certain places whole formations were stripped away. It may be that in this way the Leadville blue limestone was removed over the Lenado area, and that the succeeding deposition of the Weber shale took place immediately upon the dolomite. The third supposition has fully as strong evidence in its favor, however, as has the second, for the contact of shale and dolomite is invariably, not only in the Lenado area, but throughout the whole district, a fault contact, and its character shows that the movement along it has been very great, the amount of brecciation being greater than would result from a slight movement. In a fault of so great magnitude it would be very easy for the plane of greatest movement to deviate locally from the plane of the bedding, and this deviation would produce the differences in the rocks on both sides of the fault which have been observed. A very slight deviation of this kind might, by faulting, remove whole formations.

It may be possible that both the latter suppositions are in a measure true, and that some of the lack of uniformity results from an unconformity below the Weber and some of it from faulting. The facts, however, are sufficient for most purposes, namely, that in the contact between the Weber and the underlying rocks there has been invariably, so far as observed in this district, a fault of great actual displacement which, on account of its parallelism to the bedding, or close approach thereto, does not exhibit any

striking changes in the rocks lying on either side of it; that along this fault there appear and die out gradually, owing to its character as above described, comparatively slight discordances, so that at one point the Weber shales rest against the blue Leadville limestone and at other points against the Leadville dolomite; and near Hunter Creek the shales rest against the Parting Quartzite and the Silurian dolomite. This fault has been more important than any other one thing in determining the deposition of minerals throughout the whole Aspen district.

The Silver fault originated earlier than any of the other main structural disturbances in the district, with the exception of the folding. It is supposed that it took place at about the same time with the folding, and that it represents the slipping of one formation over the other in their endeavor to accommodate themselves to the new conditions.

East-west faults.—There are shown on the map two faults having a general east-west trend. These evidently belong to the same system, and there seems to be more of them in the district just north of the northern end of the map, running in the same direction. The chief of these two faults is called the Lenado fault. It has, in general, an east-west trend; and its dip is always steep, often approaching the vertical. In the Bimetallic tunnel it dips steeply north, and since the downthrow is on the north side, the fault is normal. This northerly dip causes the outcrop to recede in a southerly direction toward the west, so that it runs from the Aspen Contact mine in a southwesterly direction. In the Aspen Contact and the Leadville mines, however, the dip is nearly vertical, and even slightly overturned, so that it is steeply toward the south; in this case the fault is reversed, and, from its course east of the Aspen Contact mine, it may be judged that its southerly dip persists to the eastern edge of the area mapped.

This fault may be traced throughout most of its distance across the area. It was first observed in the bend in the road above the Bimetallic tunnel, where the Leadville dolomite comes into contact with the hard black Weber limestones. This contact is one which normally appears throughout this district as the Silver fault, which has led to a great deal of confusion among the miners. But in this case the fault cuts across the formations diagonally, while the Silver fault is always nearly or quite parallel to them. The true Silver fault runs into the Lenado fault very near the point mentioned, and is cut off, being displaced so that its continuation on

the northern side of the fault is nearly three-quarters of a mile away to the northeast. The Lenado fault is cut in the Leadville and Aspen Contact mines. Just above the Leadville mine it is shown in the Daisy and Ajax tunnels, which run into it on opposite sides of the gulch. Farther on the fault crosses the cliff on the south side of the granite gateway, in the little sag shown in Pl. XI, and from here apparently runs across the gulch in granite so as to cut off the quartzite on the northern side of the canyon. This last point is not shown on the map, but may be seen in Pl. XII.

This fault, as estimated in Section B (Atlas Sheet XX), has about 1,300 feet vertical downthrow on the north side. The result of its displacement, as seen on the map, is a shifting of the formations to the east on the north side. The formations exposed on the south side of the fault abut on the north side always against formations which are stratigraphically above them. Thus, at the Aspen Contact mine, Cambrian quartzite on the south lies against the Weber shales on the north. There are in this place, as probably all along the fault, a number of parallel slips, which are close together, and which divide the total throw between them. In the Aspen Contact mine there are two faults close together, the most northerly of which has shale on the north side and dolomite on the south side, while the one next south has dolomite resting against quartzite. In the general description and mapping, however, these parallel faults are considered as one, and it is in this sense that the statement that the shales rest directly against the quartzite must be taken.

It is probable that the total displacement of the rocks occasioned by this fault was actually a nearly vertical downthrow to the north of about the distance mentioned, without any great lateral movement, for the lateral offset of the beds as now seen in outcrop is almost exactly the amount by which the beds would separate from the results of a vertical throw. This arises from the fact that the beds all have a steep dip of 35 or 40 degrees to the west, so that the downthrust of the formations on the north side of the faults causes the contact to advance a certain distance to the east, in a direction opposite to that of the dip. The amount of this advancement depends upon the angle of the dip of the beds, and upon the vertical throw. The distance by which the outcrops of such beds would travel to the east on the north side of the fault has been computed at an average dip of 30

degrees to the west and a vertical downthrow of 1,300 feet on the north, and is very close to the actual separation.

The distance by which formations would be separated by such a fault depends upon the angle of the dip, as observed, for the flatter the dip the greater will be the resulting distance. It therefore happens that in the eastern end of the area the formations are farther separated than they are a little farther west, for toward the west the dip becomes steeper and the apparent lateral displacement less. This may be noted in the distance between the contact of the Weber and the Maroon on the two sides of the fault. It is very likely, moreover, that toward the west the fault actually decreases in throw, the stress which in the more rigid rocks was relieved by actual displacement being partly taken up by interstitial movement in the loose sandstones. Thus it is probable that the fault loses most of its throw in traversing Red Mountain, for in the shales on the west side of Castle Creek fault there is no evidence of any large amount of displacement. (See Section B, Aspen district map, Atlas Sheet VII.)

Of the east-west faults which appear north of Lenado, only one is shown on the map. This fault has an upthrow to the north of about 600 feet. (See Section G, Aspen district map.) In this way the dolomite on the south side is brought into contact with the granite on the north. The section just referred to shows throughout this area an uplifting of the beds along this faulted zone, which has somewhat of a correspondence with the similar uplift in the faulted area of Aspen Mountain and Tourtelotte Park, and is made conspicuous by the fact that in the Hunter Park district, which lies to the south, between Lenado and Aspen, there is no evidence of such disturbance.

In point of age these east-west faults, of which the Lenado fault is typical, are evidently younger than the Silver fault, since they displace it in the same degree as they do the rock formations. Another fact which is significant as to their age is that in the case of the Lenado fault there is absolutely no evidence of mineralization throughout the most of its extent. As cut in the Bimetallic tunnel, for example, there is no trace whatever of its having been the channel of circulating mineral-bearing solutions. An apparent exception to this is in the Aspen Contact and Leadville mines, where much valuable ore has been taken out along the fault, and in these localities all the ore which has been shipped from Lenado has been found.

It is the opinion of those who have worked these mines, however—and their opinion has been agreed to by the writer, after careful examination—that the broken and bunchy condition of the ore indicates that it was not formed in place, but has been dragged up along the fault from some other locality. The usually barren condition of the fault goes to show that it originated later than the ore deposition, and the conclusions which have been arrived at in regard to the ore in the Aspen Contact and Leadville mines point in the same direction.

Another slight point in the determination of the age of this fault is the topography. Where the fault cuts across the top of the cliff on the south side of the canyon, it forms a groove instead of a scarp. This is evidence that there has been no movement of importance since the Glacial period. The age of the fault is therefore determined as postmineral and pre-Glacial.

DESCRIPTION OF SECTIONS.

SECTION A.—On the eastern side of this section, which, like all other east-west sections, looks toward the north, the slight anticlinal structure, as exhibited in the cliffs above Lenado, is shown. The various formations represented in this section are actually visible, for in traversing this line one passes from Cambrian quartzite and the Silurian dolomite into the Parting Quartzite, which outcrops on the side of the hill and in the bottom of a little gulch, as indicated; then across a slight thickness of Leadville dolomite to the Silver fault, which is encountered at the bottom of the gulch in which the Tilly shaft is located. Farther on are the westerly dipping Weber beds, and overlying these the whole thickness of Maroon sandstones, with thin-bedded limestones and shales, while at the extreme western end of the section comes the assumed contact between the Maroon and the Triassic beds. In this section the thickness of Leadville dolomite between the Parting Quartzite and the Silver fault is very slight, probably about 100 feet. This may be due to the faulting, as previously explained, or possibly to the erosion which took place previous to the deposition of the Weber rocks.

SECTION B.—This section is taken across the Lenado fault. Its eastern end is in granite, and it runs west into the steeply dipping Cambrian quartzite. After passing across the upturned edge of the quartzite to the lowest beds of the Silurian dolomite, the Lenado fault is encountered,

which brings down the Weber shales. Below the shales on the north side of the fault, which is the west side as shown in the section, the Silver fault and the Leadville dolomite have been computed to be present at about the depth represented, so that the throw of the fault at this point is about 1,300 feet. The Weber shales are crumpled and folded against the fault, as shown. Farther west is the usual succession of Weber shales and Maroon sandstones, with at first a gentle and finally a slightly steeper dip.

HUNTER PARK SPECIAL MAP.

The Hunter Park district is a comparatively isolated area lying between the Lenado and Aspen districts. It offers comparatively few difficulties in mapping, on account of the simplicity of its structure. Most of the southeast portion is in granite, while most of the northwest is occupied by the red sandstones of the Maroon formation. In the northwest corner of the map the Triassic sandstones are represented as coming in above the Maroon. This representation is based on calculation rather than actual observation, for the difference between the Maroon and the Triassic sandstones is so slight that the actual contact can scarcely be located in any case.

Between the area occupied by the granite on the one hand and the sandstones on the other there is a narrow zone extending continuously with unbroken northeast course across the district. Throughout this belt there are numerous outcrops, affording good opportunity for satisfactorily solving the structure. The greatest break in the continuity of the rocks is offered by the drift-filled valley of Hunter Creek, which, however, is comparatively narrow. The drift in this valley is morainal in character, but has been somewhat worked over by stream action; hence it has become of some agricultural value.

Pl. XV gives a fairly good idea of the general aspect of the Hunter Park region. The view was taken from a point at the southwest corner of the area mapped, looking northeast. The hill in the foreground to the right is heavily drift covered. In the foreground to the left and in the center of the picture is the drift-filled valley of Hunter Creek, while in the distance the peculiarly rounded outlines of the hill are characteristic of this Hunter Park area, being due to extensive glacial erosion. The small

VIEW OF HUNTER PARK DISTRICT.

apparently isolated hill a little to the right of the center of the picture is in the zone which lies between the granite and the red beds. At the base of the hill to the right the granite outcrops; higher up is the Cambrian, and at the top of the hill is the Silurian dolomite, while in the peculiar gap comes in the Silver fault, and to the left of that the Weber shales. The shaft dimly shown in the gulch at the left of the hill is the Badger, which has gone down through the shales to the contact of shale and dolomite at the Silver fault. In outline against the sky at the left of the picture is shown a peculiarly rounded hill. The base of this hill, as seen in silhouette where it meets the slight westerly dipping slope on the east side, is about at the contact of Weber and Maroon. The hill, therefore, occupies the base of the Maroon formation with its alternating thin beds of calcareous sandstone and arenaceous limestone with intercalated shales. These strata dip to the west, or toward the left of the plate, and a peculiar and striking feature in the landscape is that the slight amount of vegetation, consisting chiefly of bushes and aspen trees, which has accumulated on the side of this hill, has arranged itself in symmetrical bands indicating the position of the outcropping strata. The reason for this appears to be that in the more porous beds there is a greater amount of moisture, and that the vegetation along this zone becomes more thrifty, or that the limy beds furnish more nutrition to plant life than the more arenaceous ones. This banding is best shown in autumn, when the frost gives the aspens their most brilliant coloring.

FOLDING.

In the northeast part of the district the broad outcrops of Cambrian and Silurian indicate a flattening of the strata to the east, corresponding to the fold which has been described in the canyon at Lenado. West of this flattening, as at Lenado, the beds become steeper, and in a short distance the dip becomes uniform, and so continues to the western edge of the district. This flattening of the strata to the east is not shown in the central and southern parts of the district, for here erosion has removed the upper part of the fold, leaving only the steeply dipping beds below. Through the whole section west of the granite, in these portions of the district, the uniform dip to the west is probably about 45 degrees, being less in some places and greater in others.

FAULTING.

Silver fault.—The Silver fault is traceable across the district, either by outcrops or, more accurately, by underground exploration. It has always been well recognized that this plane is one of the most favorable localities for prospecting, and so there is a continuous series of shafts or other workings set at a short distance from one another along the whole line of the fault. These workings always reveal at this plane the broken and shattered zone, which shows this to be a true fault contact. The outcrop of this fault, as shown on the map, is not strictly parallel to the formation lines, although in a general way it is so, and the deviation from parallelism illustrates its fault character. In the northern part of the district the fault lies between the Weber shales and the Leadville dolomite, and there is lacking only the Leadville blue limestone to make up the entire section. In the central part, however, the Silver fault tends to approach the underlying strata toward the south, so that it cuts across the Leadville dolomite into the Parting Quartzite, and at a point near the top of the isolated hill seen in the accompanying plate it cuts across the Parting Quartzite into the Silurian dolomite. These different formations come successively to rest against the shale, which persists on the northwest side of the fault. It is probable that the occurrence of Weber shale resting upon Silurian dolomite, as found in the vicinity of the Badger mine, is continuous across the creek under the drift covering, for in the workings on the southern edge of this drift we find the same conditions. At a point near the southern termination of the outcrop of the Silver fault this fault cuts upward again across the strata, revealing the whole of the Silurian dolomite, then the Parting Quartzite, and finally cutting up into the Leadville dolomite. It does not, however, get to the top of this last formation, and in the whole Hunter Park district there was found no trace of the Leadville blue limestone.

Lenado fault.—The Lenado fault is shown on the northern part of the map, but it is not actually traced across this district. From the trend of the fault when last identified it must cut the Hunter Park area in about the line indicated, and from its great throw at Lenado it must persist for a long distance. In the thick red sandstones, however, which present no well-marked difference from top to bottom, it is impossible to follow any fault, and an additional difficulty is introduced by the drift covering. The probable effect of the fault is to bring the Triassic beds on the north

against the Maroon on the south, in the northwestern corner of the area, as shown on the map.

From the Lenado fault there was not discovered any noteworthy break, with the exception of the Silver fault, until the southwest corner of the district was reached. Here there is a slight break marking the extreme northeastern border of the area of complicated faulting which extends throughout the whole southern part of the district examined. This area of extreme faulting, which is accompanied by a domelike uplift, is best developed in the district shown on the Tourtelotte Park special map, in the northern part of which it seems to attain it greatest importance. Northward from this point faults are strikingly developed over the whole of Aspen Mountain; they are still well marked, but to a slighter degree, on Smuggler Mountain, and they die out in the southwestern corner of the Hunter Park area. The most northern of these faults observed is seen in outcrop on the hill above the St. Joe and Bertha shafts. On this hill the contact of the granite and quartzite is offset to the west on the north side, as shown by its outcrop, about 200 feet. From this point the outcrop of the fault passes into the granite on the east and under the drift covering on the west. In the Alta Argent mine, however, there is cut in the Cowenhoven tunnel a fault which is probably identical with the one seen in outcrop in the hill. This fault has a displacement to the west on the north side, which has been approximately estimated as aggregating 100 feet or so. This separation, however, has not taken place along any single plane, for in place of a single slipping surface there are many parallel fractures, constituting an intensely sheeted zone of some thickness, and the displacement has probably been distributed among these separate planes. The fault has been located only in these two places, and is represented on the map as dying out at both ends—to the east in the granite and to the west in the sandstones on the north side of Hunter Creek. In these comparatively homogeneous rocks the disturbance could not be followed, and so it can not be told whether the fault is actually persistent or not. It seems probable that the actual direction of movement along this fault was down to the south, combined with some westerly lateral movement on the north side, so that on the slipping plane of the fault, which, as shown in the Alta Argent mine, is vertical, with a northwest-southeast trend, the movement was diagonally down to the southeast on the south side. The lateral movement

in faults is well shown in the case of the neighboring Della fault, which has a different slipping plane, but a similar direction of movement.

Age of Alta fault.—In the mines there are some ore shoots which apparently have formed along fractures belonging to the Alta fault system, but these are on the outskirts of the chief displacement and have only a slight movement. Along the main fault there does not appear to be any mineralization, but there are, instead, fissures and open watercourses. It may be judged from this that the fault movement probably began immediately before the mineral deposition, but was mostly developed at a later period. These conclusions in regard to age are almost surely true in the case of the neighboring Della fault.

Della fault.—The Della fault was not actually located in this district, but was extended across the map on account of calculations based on data obtained in mine workings on Smuggler Mountain. Its location, therefore, is not of necessity exactly correct. It is represented on the map as having a throw similar to that which it possesses in Smuggler Mountain, but with the amount of this throw diminished; and it is represented as dying out in the granite. These are, however, assumptions. This fault will be described in detail in considering the geology of Smuggler Mountain; but it may be stated that its apparent displacement is to the east on the south side; that its trend is east and west, and its dip about 30 degrees to the south, and that the striæ along this plane show that the movement has been to the southeast on the south side of the fault, at an angle of about 45 degrees to the horizontal.

RÉSUMÉ OF THE STRUCTURE OF HUNTER PARK.

First. The first deformation of the original strata was a heavy folding. This resulted in a general steeply dipping monocline, which in the eastern part of the district, near the contact with the granite, shows a flattening of the dip and an approach of the strata to the horizontal. But the beds thus dipping are often removed by erosion.

Second. Almost contemporaneous with the folding was the development of the Silver fault, which runs very nearly parallel to the bedding, but often cuts across it at a slight angle so as to remove whole formations. Along the southern end of this fault many ore deposits exist; its age, therefore, is premineral.

Third. Next came the development of east-west faults, which seem to be referable to two divisions The Lenado fault is apparently referable to a distinct fault district which begins at the northern part of the Hunter Park area and extends northward. The southern division begins with the Alta fault, the extreme outlier of the complicated faulting which is centralized in the Tourtelotte Park area. All these faults have a general east-west trend, although no two of them are strictly parallel. The Lenado and the Alta faults are nearly vertical, but differ in trend, while the Della is a flat fault, pitching to the south. In point of age these three faults seem to be nearly alike, all of them having had an important movement since the ore deposition, and so being in large part postmineral. The Della, however, as will be shown, existed as a well-marked fault previous to the ore deposition, while the Alta fault appears to have been very slightly developed at this time, and there is no evidence that the Lenado fault even originated before the mineralization.

DESCRIPTION OF SECTIONS.

(ATLAS SHEET XVIII.)

Section A.—On the east side of the section the beds flatten to correspond with the Lenado fold, and the various formations are well exposed in outcrop. The Silver fault in this section separates the Leadville dolomite from the Weber formation. The contact of Maroon and Weber is well shown in outcrops, and from this contact west there is nothing but Maroon beds in the section. The Lenado fault has been calculated to occupy about the position shown.

Section B.—The whole eastern part is in granite. On the hills along this section, especially on the western part, there is much drift covering, but the drift has been represented only in the valley of Hunter Creek, while the rest of the area is represented by its bed rock.

The hill just west of Hunter Creek is shown in Pl. XV, and has already been described. In the gulch west of it the Silver fault crops, and a little west of this the Badger mine has gone down to the fault. On this hill there outcrops above the granite the Cambrian quartzite, which is overlain by the Silurian dolomite. The dolomite is here quite thin, and is separated from the Weber shales by the Silver fault. The thickness of shales in this section appears to be abnormally slight, but whether this is due to the action of the Silver fault or to original deposition can hardly be stated. The whole western end of the section is in the Maroon red beds.

Section C.—This section shows at the outcrop of the contact of granite and Cambrian quartzite a slight flattening of dip, but the flatter beds above have been removed by erosion. Above the Cambrian there lies nearly the whole thickness of the Silurian, but, as in the previous section, the dolomite rests in outcrop against the Weber shales. The Parting Quartzite does not outcrop, but in the St. Joe shaft, which cuts the Silver fault, it was discovered underground. The peculiar curve of the Silver fault at this point, as represented on the section, and the manner in which it cuts across the upturned strata, have actually been developed in the mine workings. The contact of Weber and Maroon comes under the drift-filled Hunter Creek Valley, so that the first outcrops on the north side are of Maroon sandstones.

The section has been continued beyond the limits of the Hunter Park map across the northwest corner of the Aspen special district and a little up the side of Red Mountain, so as to give a more general idea. The whole of this mountain side is in the uniformly dipping Maroon beds.

THE ASPEN DISTRICT MAP.

OUTLINE OF STRUCTURE.

In order to combine and to bring out the connection between the special parts of the general mining region which have been described in the 800-foot maps, a single large map was constructed, covering the areas of these smaller ones and furnishing some additional information. In reducing the 800-foot maps to the half-mile scale many of the details were omitted, and the structure was thus generalized, but in all cases the distinctive features were carefully preserved. In the complicated areas this was especially necessary, as, for example, in Tourtelotte Park, where the faults are so close together that they can not well be represented on the scale of half a mile to the inch in such a manner as to be intelligible. A variation in the plan of this map from that of the maps on the 800-foot scale is the omission of the Recent or Glacial formations. In the space between Aspen and Smuggler mountains, where the valley is filled with deep glacial material, the connection between the rocks on the two sides of the valley is not always well understood by the mining population. As shown in this map, the relation of the two is not very difficult to conceive, the apparent great difference being due to the uplift of the strata on Aspen

Mountain, which causes the outcrop of the sedimentary beds to advance to the west. The north-south faults of the Aspen system are shown dying out under the valley of the Roaring Fork. The exact point at which these die out is, of course, not known, and they may extend farther into the Maroon formation than has been represented; but in this formation there is no means of tracing their extension, on account of the similarity of the beds on either side.

This joining of the several maps brings out more clearly the salient features in the structural geology of the district. As one looks at the map and observes the comparatively narrow zone along which outcrop the beds lying below the Maroon and above the basal granite, the most distinctive feature is the contrast between that part of the belt north of the town of Aspen and that part to the south. Throughout the Hunter Creek district the beds maintain comparatively uniform strike and dip, and are not broken to any extent by cross faulting. Southwest from this there comes in a remarkable change at the town of Aspen, which is marked by the sudden advance of the outcrops toward the west, by the change in the strike of the beds from northeast to nearly north, and by the beginning of a series of important and complicated faults. All these disturbances appear very suddenly, and may be said to be centralized in the northern part of the area of the Tourtelotte Park special map. The sudden advance of the outcrops toward the west is due to the presence of the uplifted dome, which apparently has its highest point in the northern part of Tourtelotte Park, but has a steep face toward the north, so that it is practically wanting in the Roaring Fork Valley. The change in the strike of the beds has no apparent connection with this extremely local uplift. If one regards, however, the general line of contact between the granite and the overlying beds from the northern part of the Hunter Creek area to the southern edge of the district, it will be seen that this outcrop forms a single large curve. Along this line the beds have a uniform dip away from the granite, except where, as in the Tourtelotte Park area, this dip has been locally altered. It may be, therefore, that all these beds are lying upon the flanks of an uplifted dome, which was larger and had a more uniform and a gentler uplift than had the more concentrated disturbance in Tourtelotte Park, and that the Tourtelotte Park uplift was but a smaller and comparatively more violent manifestation of the same uplifting force which caused the larger

movement. At the extreme northeastern corner of the district there is an area which is also faulted, and between this and the northern part of the Hunter Park area the strike of the beds becomes more nearly north, deviating considerably from the normal trend across Hunter Park. This change in strike indicates an uplifting of the strata shown in Section G, Atlas sheet VII. This uplifting is accompanied by faulting, and as ore has also been found in this district, it may be that the disturbance was similar to that of the Tourtelotte Park uplift. In the undisturbed region between these two uplifts the rocks, so far as yet known, are practically barren of mineral values.

The uplift of Tourtelotte Park and Aspen Mountain is one of the most interesting structural features in the district. By comparing the amount of uplift, as seen in the longitudinal section, with the corresponding difference in throw of the Castle Creek fault at various points, it is seen that all the uplifting has taken place subsequent to the formation of the fault, and that the beds on the east have moved upward along it. The uplifted region stopped short at the fault, the beds on the west side having had no corresponding movement. On the west side the beds have a uniform northerly pitch, which reveals successively lower strata toward the south. South of the northern limit of the fault, as shown on the map, the formations occur in normal succession, from the Laramie, through the Montana, Colorado, and Dakota of the Cretaceous, the Gunnison formation of the Jurassic, the Triassic, the Maroon and Weber formations, and even the intercalated sheet of porphyry, which is found in the lower part of the latter; this porphyry outcrops in the extreme southern part of this district, as the Laramie does in the extreme northern part.

The beds east of the fault, however, have no uniform pitch, but show differences at different points, forming a strong contrast with the uniformity of the beds on the west. From the northern part of the district to Red Butte there is a gentle northerly pitch, which is somewhat less than that to the west of the fault at this place, so that the amount of displacement increases northward from Red Butte. South of Red Butte there is a sudden steepening of the pitch on the east side. Near the point where the beds begin to pitch most steeply there comes in a series of faults which, like the increase in pitch, operate to upthrust the beds on this side of the fault. Thus West Aspen Mountain is simply an isolated block which has been uplifted above the surrounding strata between certain of these faults.

On the northern edge of West Aspen Mountain there is shown on the map a series of cross fractures, which represent the slipping of the rocks on the northern end of this block over each other while the southern end of the block was being upthrust. The bending of strata and the faulting were apparently developed at the same time and extend over practically the same area, so that they are both probably the manifestation of a single force, which tended to push the beds upward. The point of greatest uplift, which is situated at about the top of Aspen Mountain or in North Tourtelotte Park, is also the point of most intense faulting. The steep northerly pitch on the north side of Aspen Mountain continues up to the top of the mountain, or to the point of greatest disturbance. At this point the attitude of the beds changes again somewhat abruptly, so that they have no pitch, or a slight southerly one, and this attitude persists to the southern edge of the district. Since on the west side throughout this same district the uniform northerly pitch continues, it results that from Aspen Mountain the displacement of the Castle Creek fault steadily diminishes toward the south.

The amount of faulting at Red Butte has been computed at about 2,600 feet. On Aspen Mountain, near the center of greatest uplift, the section shows a throw which has been increased by the differential dip of the beds to the east and to the west of the fault, and by the upfaulting of blocks immediately to the east to about 9,000 feet. South of this point, however, the throw steadily decreases again, until near the southern edge of the area it is only about 2,600 feet. It appears from this that the amount of movement along the Castle Creek fault has been about the same at Red Butte and at Queens Gulch, while in the intervening space there is a great, but purely local, increase, so that the throw becomes three and four times as great as in these two places. This increase is apparently independent of the beds on the west of the fault, and is caused simply by the uplifting of the dome which has been described on the east side, and which has its center of greatest disturbance at the point of maximum displacement along the fault.

In the interval between Roaring Fork and the top of Aspen Mountain, the longitudinal section (Section G, Atlas Sheet VII) shows an uplift along the strike amounting to about 5,000 feet, caused by the combined effects of folding and heavy faulting. The difference in the displacement of the Castle Creek fault between the point where it is displayed at Red Butte

and a point opposite the top of Aspen Mountain, which is the point of greatest disturbance in the uplifted beds lying to the east, is about 6,400 feet, as nearly as can be estimated. The amount of uplifting as shown by the longitudinal section, therefore, is amply accounted for by the differential movement which has gone on along the fault. The inference from this is that the main uplifting and faulting in this disturbed area has gone on since the formation of the Castle Creek fault. The amount of increase in the throw of the fault, producing its maximum displacement of 9,000 feet, is due mainly to the increased steepening of the dip on the north side of Aspen Mountain and to the associated faulting, while to the south of the region of greatest displacement the dip changes, so that the rocks on both sides of the fault tend to converge, and therefore the throw steadily decreases. The local and enormous increase in the amount of displacement is, therefore, to be entirely accounted for by this local uplifting on the east side of the fault; and there is no evidence that the beds on the west side have had any part in this movement.

The summit of the dome is traversed by an intricate system of faults, which have their greatest development at the point of greatest uplift, but are conspicuous and important over the whole of the uplifted area. North of this area they disappear as quickly as the uplifting itself, while on the south they disappear somewhat more slowly, as does the uplifting. The faults may be divided into two chief sets, one parallel to the axis of greatest disturbance and to the Castle Creek fault, and a second at right angles to the first. It is probable that both these originated simply as sets of fractures and were formed at about the same time, but the maximum displacement along each took place at different periods. This period must be worked out from every fault separately, for movement has been going on continuously from the formation of this uplift to the present day. As a general rule, those faults which were parallel with the longest axis of the uplifted dome, or which run in a north-south direction, had their greatest movement at an earlier period than the other set; and the movement along these has been greater than that along the others, as might be expected along faults developed parallel with the axis of greatest disturbance. The east-west faults have less importance, and the amount of their throw in no case attains anything like the proportions which are found in several of the other set.

The intersection of these two systems of faults has produced many blocks, and, in the process of uplifting, these blocks have often been moved one upon the other in such way as to result in a very complicated structure.

The portion of the district which lies to the southeast of the areas of the detailed maps which have already been described is entirely in granite and without important structure, so far as the present study goes, and so need not further be dwelt upon. It is all glaciated and in places thickly covered with morainal deposits. That portion which lies to the northwest of the special areas includes, besides the formations already described, the upper part of the Triassic, which consists of massive deep-red sandstones, the sandstones and variegated shales of the Gunnison formation, and the heavy sandstones or quartzite of the Dakota, which is throughout this region the lowest member of the Cretaceous. Above these comes the Colorado formation, which is capable of division into its two members, the Benton and the Niobrara. Above the Niobrara comes the Montana formation, consisting of a great thickness of black shales, and above this the lower part of the Laramie, which is the youngest pre-Glacial formation shown in the district. These formations are crumpled into folds, in part overthrown, in the immediate vicinity of the Castle Creek fault, but these die out in a surprisingly short distance westward, the beds assuming a horizontal or gently dipping attitude. The chief feature in the folding immediately west of the fault is a northerly pitching syncline. In the central part of the district this syncline is closely compressed and overturned, while in the northern and southern parts it is open. The general structure of this fold and its relation to the Castle Creek fault may best be seen from the study of the accompanying sections.

DESCRIPTION OF SECTIONS.

(ATLAS SHEET VII.)

Section A.—The eastern part of Section A has already been shown on a larger scale in a cross section through the Lenado maps, where the steeply dipping Cambrian and Silurian rocks are seen to lie upon the uplifted granite. These are cut off by the Lenado fault, which brings the Weber formation in outcrop against the Parting Quartzite. Westward from this outcrops the whole of the Maroon formation, which is overlain by the Triassic. The Triassic is continuous from the point of its contact with the Maroon to the Castle Creek fault. There is probably, as is shown by

observation farther north, a slight syncline in the red beds against the fault at this point. On the west side of the fault there outcrops the top of the Montana formation, and a short distance farther west comes the contact of Montana with Laramie. The throw of the fault at this point is estimated at about 5,500 feet. The beds to the west form a comparatively shallow syncline, which, so far as is known, is not at all overturned. The Laramie sandstones which outcrop along this section show that this fold is really in the nature of a synclinal basin, for the dip is toward the center on all sides.

Section B.—In this section the Lenado fault is shown with a lessened throw. This location of this fault was not actually made in the field, but by extension from its known outcrop. In these uniform red beds there is no possibility of determining accurately any extensive fault. As in Section A, the steeply dipping monocline which lies to the west of the granite core of the Sawatch changes into a gentle syncline at the Castle Creek fault. On the west side of the fault the shales of the Montana outcrop, while a very short distance below the Niobrara, Benton, and underlying formations are represented as running into the fault. This representation is based upon the actual outcrop of these beds a little farther south, where the general northerly pitch of the fold brings them to the surface.

Section C.—This section illustrates the nature of the Castle Creek fault and the folding in the beds on both sides of it. Nearly all its features are based on reliable data. The slight synclinal fold in the red beds east of the fault is shown by outcrops on the flanks of Red Mountain. The prominent hill to the west of the fault is Red Butte, and on the steep side of this hill the different formations as represented, namely, the top of the Triassic, the Jurassic, the Dakota, the Benton, Niobrara, and the Montana, are actually found in outcrop, lying in the reverse of their usual order and dipping to the east. The representation of the rocks west of Red Butte is based upon an almost continuous section along the river bank and railroad cut. The fold, as shown by these exposures, becomes very gentle a short distance west of the fault, so that the beds have only a slight easterly dip. A short distance west of this section the dip gradually changes so as to form a slight anticline, the western limb of which has a gentle westerly dip.

Pl. XVI is a view taken looking west from near Red Butte. In the center of the foreground is the valley of the Roaring Fork, while the ridge

CRETACEOUS AREA WEST OF RED BUTTE.

on the left is Red Butte itself, although the different formations can not be distinguished. In the distance the uniform, gentle, north-facing slope of the hills is identical with the dip of the rocks which form the north limb of the gentle anticline referred to.

The section as described seems to show that at the point of maximum disturbance there once existed a sharp, compressed anticline, which was overturned to the west, and that along the axis of this anticline the great fault developed. It is a marked feature of this folding, as compared with that of other closely folded areas, that it is confined to a narrow zone, east and west of which the beds are comparatively undisturbed.

Section D.—Section D passes through the central portion of the uplifted area in Tourtelotte Park. In this area are shown the minor folds and the numerous faults generalized from the special maps, and east of this there is nothing but Archean granite. In this section the Castle Creek fault separates the granite from the Triassic sandstones, its vertical displacement being about 9,000 feet. The beds west of the fault are still overturned, having a steep easterly dip. The structure of the ridge which lies between Maroon Creek and Castle Creek shows that here there is a slight anticlinal which has no counterpart in Section C. In the western part of the section the beds have a gentle easterly dip, which corresponds to the similar dip in the western part of Section C. The outcropping Dakota sandstone runs along the surface west of Maroon Creek.

Section E.—The extreme east end of the section is somewhat beyond the limits of the map, being the point where Difficult Creek runs into Roaring Fork Valley. At this place is granite, which continues to near the top of Richmond Hill. The strata exposed on this hill belong to the lowest portion of the sedimentary series, and constitute a west-dipping monocline. The faulting connected with the Tourtelotte Park uplift is also shown. West of the Castle Creek fault the beds are still slightly reversed, having an easterly dip which approaches the vertical. It is near this point, however, that the beds overturn and resume their normal succession. The Weber formation outcrops directly west of the fault, being brought up by the northerly pitch of the fold, and from here to the top of the mountain between Castle Creek and Maroon Creek there is apparently nothing but Maroon beds, but the top seems to be formed of the heavier and brighter red Triassic sandstones. The syncline, in the bottom of which, as in the previous section

(Section D), Castle Creek flows, has become broader and is slightly overturned against the fault, while the anticline between Castle and Maroon creeks is still present and has become shallower and broader.

Section F.—Just east of the eastern end of Section F granite outcrops, the distance between it and the Castle Creek fault being very slight. The sedimentary beds on the east of the fault constitute, as in Section E, a gentle, westerly dipping monocline. Immediately west of the fault the beds have a steep but uniform westerly dip, and lie in their normal succession. Owing to the northerly pitch of the fold, there are brought into outcrop Weber shales, with the intercalated sheet of porphyry which usually lies at this horizon. The Weber formation is overlain by the Maroon, which is continuous to the end of the section, with the exception of the very top of the mountain between Castle Creek and Maroon Creek, where the Triassic probably comes in. The general structure of the fold along this plane of section is that of a well-marked but open syncline, in the bottom of which Castle Creek lies. The relative structure of the beds on the east and on the west side of the fault along these different sections is obscured in large part by the subsequent local uplifting and faulting throughout the southern part of the area immediately east of the Castle Creek fault. But on comparing this section (Section F) with Section C, it is seen that on the disappearance of the overturned syncline on the west there also disappears the slight open syncline on the east; so that from the compressed folding at Red Butte there is a change to a more simple structure.

Section G.—Section G is drawn as nearly as possible parallel with the general strike of the beds throughout the district, and reaches from the extreme northeastern corner of the district shown on the map to the western side of the Castle Creek fault south of Aspen. It shows in its central part a nearly horizontal intersection with the different beds, while the southernmost part is conspicuous on account of the uplifting and faulting. In the northeastern part there is a similar but not so sudden uplifting, which is also accompanied by faulting, although to a less degree. The relation of the Silver fault to the sedimentary beds, as it varies from point to point, is better seen here than in any of the cross sections. In the northeastern part of the section it separates the Weber shales from the Leadville dolomite, and the distance between the fault and the Parting Quartzite is comparatively slight. In the Hunter Park area the fault cuts

CASTLE CREEK VALLEY AND RED MOUNTAIN.

down into the formations, so that there is found on its lower side the Silurian dolomite, with the Cambrian quartzite not far below. The Weber formation, however, is still on the upper side. This cutting down of the fault is only local, for farther southwest it cuts up across the Parting Quartzite into the Leadville dolomite. The line of this fault throughout the Hunter Park region, as compared with the line of the formation beneath, is suggestive of unconformity, and, as has been stated, there was actually some unconformity at this period. It is certain, however, that this plane is representative of a true fault, and that the fault is a heavy one, for it is marked by great brecciation. It may be that some unconformity existed previous to the faulting, and that the disturbance simply caused the Weber sediments to slide over the beds which lay beneath, or it may be that the disparity in the beds was not always so strongly marked as now, but was brought about by the removal of some formations through the faulting. The only positive facts are that there was a heavy fault along this plane, and that along this fault certain formations have locally been removed.

In the southwestern part of the section is a heavy porphyry sheet, which lies very close to the Silver fault, being separated from it only by a thin and variable sheet of broken shale. Only the main faults are shown in this section, such as the two chief faults at Lenado, the Della fault on Smuggler Mountain, and the principal faults of Aspen Mountain. These are, however, such as bring out the actual structure best.

By putting all the cross sections together the general structure of the beds on the west side of the Castle Creek fault is seen to be about that of a permanent synclinal fold. In Section F, in the southern part of the district, the fold is deep, broad, and open. Toward the north it becomes somewhat shallower, but also more closely compressed, and is overturned throughout the central part of the area, while in the northern part it again becomes open, and is here still shallower.

The fault itself is continuously traceable throughout the whole district. In the extreme southern part, in Section F, its throw is only 2,600 feet, while in Section E it has increased to about 6,300 feet, and in Section D to 9,000 feet. This last point, which is opposite Aspen Mountain, is the point of maximum throw. Pl. XVII gives a view looking down Castle Creek across the Roaring Fork Valley to Red Mountain. On the right-hand side

of the valley, where Castle Creek runs into Roaring Fork, is the point of West Aspen Mountain. The rocks on this mountain which are shown in the picture are Archean, Silurian, and Cambrian, and the Castle Creek fault runs along the base of the mountain, parallel to and just east of Castle Creek. The whole of the left-hand side of the valley is of bright-red Triassic sandstone, which has a dip of 50 degrees or so toward the east, forming part of the overturned fold which lies against the fault. From this point the fault pursues a comparatively straight course, crossing the Roaring Fork Valley and running across the southeastern end of Red Butte.

Pl. XVIII is a view taken from near Red Butte on the northeast side of Roaring Fork. The river and the butte occupy the foreground. In the center of the picture is the flat Roaring Fork Valley, with Aspen at the left side. The even terrace which the river has carved in post-Glacial time is very well seen. In the background is Aspen Mountain, the projecting ridge of West Aspen Mountain just left of the center. The woody gulch on the right side of Aspen Mountain is Keno Gulch, across which, as described, the Castle Creek fault runs. In this picture the Castle Creek fault runs from Roaring Fork, across the southern point of Red Butte, south-southeast for 1½ miles, and just to the right of the smokestack on the lixiviating works, then swings to the south and crosses Keno Gulch, and so on out of the area represented on the plate.

From Red Butte the fault continues northward over the gently sloping western side of Red Mountain to Woody Creek. Pl. XIX shows this part of Red Mountain. The view is taken from the west bank of Maroon Creek at Red Butte. The sharp ridge in the foreground is the northwestern extension of the butte, and along this ridge the outcropping beds of the Triassic, Gunnison, and Lower Cretaceous formations dip steeply to the east and are overturned, as shown in Section C. The ridge separates Maroon Creek from the Roaring Fork, and the two streams unite just to the left of the pictured area. The fault runs diagonally across the pictured area from behind the ridge of Red Butte at the right to near the western edge of the horizon, which it crosses at about the point where the short, level outline changes to a slope. Along this mountain side the fault is often obscured by the heavy covering of glacial drift, but its course is made sufficiently clear by occasional outcrops, which show that it separates the Triassic sandstones on the east from the Montana shales on the west.

ROARING FORK VALLEY AT ASPEN, AND ASPEN MOUNTAIN.

On a hill overlooking Woody Creek the base of the Laramie is brought down on the west side of the fault, so as to abut against the Triassic sandstones on the east. From its northern termination, as shown on the map, the fault can be traced along the northeast side of Woody Creek for some distance. Its course is marked by a large amount of gypsum, which forms a continuous white zone along it. Just below Woody station there is a prominent hill jutting out from the Roaring Fork Valley on the northeast side, and through this the fault appears to run. Only a hasty examination was made, but the Dakota and Niobrara formations on the southwest appear to abut against the Triassic red sandstones on the northeast. The top of this hill is a dark, vesicular basalt; according to Holmes,[1] this basalt has risen along the fault. No attempt was made to trace the fault farther northwest than this point. The southern extension of the fault, also, from the point where it leaves the area of the Aspen district map, in the vicinity of Little Annie mine, has not been looked for, but it probably grows continually less, and if it keeps its normal course runs into granite on both sides and is lost.

RÉSUMÉ OF STRUCTURE IN THE ASPEN DISTRICT.

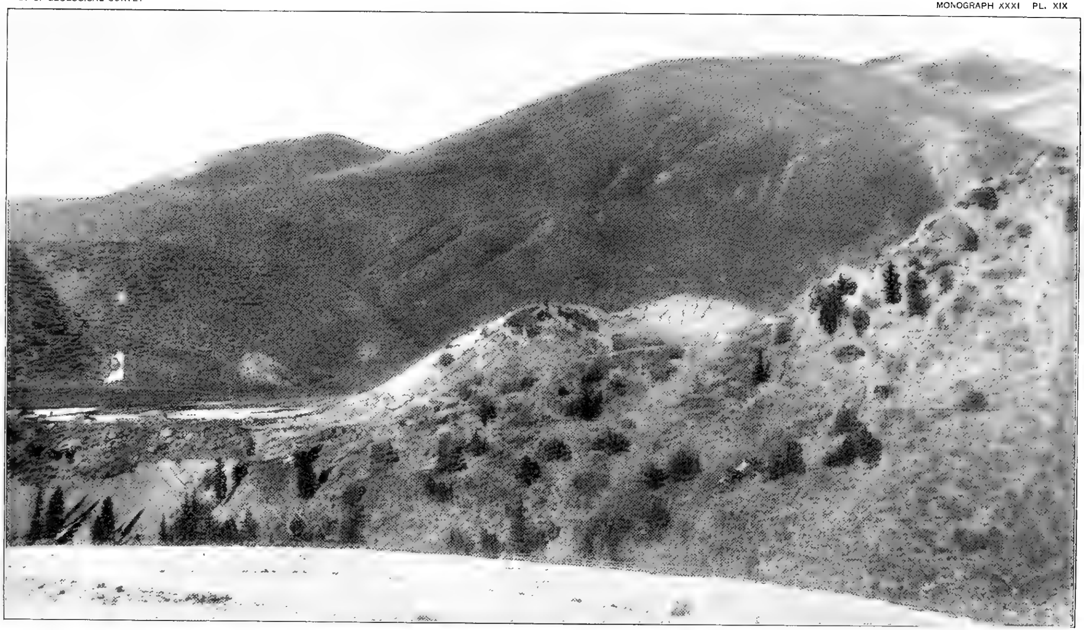
The initial disturbance in the rocks in the Aspen district seems to have been a general folding. This folding took place certainly after the deposition of the Laramie, and also after the intrusion of diorite and quartz-porphyries into the sedimentary beds. It probably followed very close, however, upon this igneous intrusion. The deformation seems to have been due to a lateral thrust which pushed the sedimentary beds against the hard resisting mass of the Sawatch Mountains. The cause of this lateral thrust was probably the uplifting of the Elk Mountains to the westward, which in turn was due to the intrusion of large masses of molten material upward into the sedimentary beds along a line of weakness. A continuation of the same force, therefore, which thrust the intrusive rocks into the sedimentary beds brought about the folding and breaking of these intrusive sheets along with the inclosing strata. The disturbance arising from the lateral thrust is restricted to a comparatively narrow zone, running parallel to the main axis of the Sawatch. The greatest folding occurred along a still narrower zone, at some short distance from the granite. Along this

[1] Report of the Hayden Survey, 1874, p. 60.

zone there was heavy folding, which resulted in the overthrust, easterly dipping, and northerly pitching folds of the Aspen district. These folds appear to have opened out to the north, and, as at present exposed in outcrop, are also open to the south. It is possible, however, that the compression was more intense in the upper sedimentary beds than in the lower ones, and therefore that those portions of the folds which are now open, in the southern part of the area, may have been closed and overturned in the overlying sedimentary beds which have been removed by erosion. Between this line of greatest folding and the granite there was a series of slight open folds, which often are hardly recognizable and again are very noticeable. West of the line of folding there is very little deformation, the disturbance dying out in a surprisingly short space, so that the beds resume a horizontal or gently dipping attitude.

The folding along this line culminated in a fault which appears to have originated along the axis of an overthrust anticline, and to have extended to the south and to the north along the line of maximum strain. This is called the Castle Creek fault.

Silver fault system.—At the time that the folding in the beds was going on, certain of the more rigid of the formations slipped upon certain others, forming a number of bedding faults. Some of these faults were parallel to the bedding, while some of the larger ones were not always parallel, but ran locally at a slight angle to it. There are many of these faults, but they are not often conspicuous, for the very reason of their parallelism with the bedding. In the Weber and Maroon formations they have not been carefully traced, although in the Cowenhoven tunnel several faults belonging to this system may be observed, a specially well-marked one occurring at the contact of the Weber and Maroon. It is probable that these faults are more important in the lower sedimentary beds than in the upper, being caused by the slipping of the strata over the underlying, more rigid granite. The most important fault of this system—the Silver fault—occurs at the contact of the Weber with the underlying formations, and in places has a certain amount of obliquity with the bedding planes. A short distance below this fault is the Contact fault, which lies between the blue limestone and the dolomite of the Leadville formation. This latter fault is apparently much slighter, and, so far as observed, is strictly parallel with the bedding. These faults of the Silver system probably originated earlier



WEST SIDE OF RED BUTTE AND OF RED MOUNTAIN.

than the Castle Creek fault, and were faulted by it. They are very important in studying the economic geology of the district, since the ore has been to a large extent deposited along them.

Tourtelotte Park uplift.—Immediately after the formation of the Castle Creek fault, or perhaps synchronously with it, there began an uplift such as would arise from a vertically exerted force. This was a doming-up of the rocks just east of the Castle Creek fault, extending north and south over a limited area. The movement did not affect the rocks to the west of the fault, and thus the throw is correspondingly increased in the region of uplift. The summit of the dome is in the northern part of Tourtelotte Park, while the abrupt north side is on Aspen Mountain and ends very suddenly in the Roaring Fork Valley; the south side of the dome is gentler, and its structure is obscured by erosion, which has brought the granite to the surface. This uplift affected the granites as well as the sedimentary formations, but in the granite there is no means of measuring it, or even of ascertaining its existence. There are indications of a similar tendency toward local uplifting or doming at Lenado.

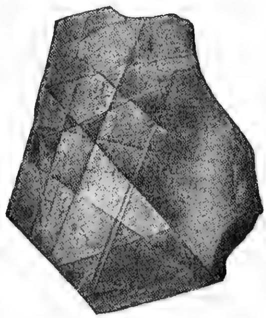


FIG. 5.—Fractures in Weber limestone.

Faulting.—With the beginning of the formation of this local dome there also began a system of local faulting, which continued from that time to the present. The first-formed system was parallel with the Castle Creek fault, and the faults belonging to it have a heavy throw, which is most pronounced on Aspen Mountain and diminishes from this point more or less rapidly to the north and to the south. At the same time there were formed many fractures without important throw, some of them being north-south and parallel with the actual faults, while others ran across in an east-west direction. In this way the summit of the dome, and, to a less extent, its sides, were profoundly fractured. Some graphic idea of this fracturing may be gained from the accompanying figure (fig. 5), which is from a photograph (natural size) of a small piece of thin-bedded Weber limestone. This specimen came from Tourtelotte Park, where faulting on a large scale is most pronounced, and it represents so closely in miniature the complicated fracturing which

this district has undergone that it seems both the minute fractures and the larger faults must have resulted from the same cause. In closely folded regions it has already been demonstrated that the slight wrinkles or flutings in rocks have an intimate connection with the more important system of folding, and may often be used in deciphering this system. On studying the fracture planes in the specimen figured, and in other specimens from the same locality, the conclusion is forced upon one that this finer structure may be taken, in a guarded way, as indicative of the more general system of fracturing and of faulting on a larger scale. Almost every feature connected with the fracturing in this specimen (and they can not all be well seen in the reproduction) finds its parallel in the peculiar system of faulting in Tourtelotte Park. The different blocks which these fractures make by intersection have been brought into relief by slight weathering, which has removed more iron from certain blocks than from others, and so produced a difference of coloring, which brings out the structure strikingly. Careful observation will show that there are not only different systems of fracture in this specimen, but movements of different ages, for some of them have slightly faulted others.

Mineralization.—Immediately following this faulting and fracturing at the beginning of the uplift came ore deposition. Ores are now universally found along these faults and fractures, either in vertical faults or, more commonly, at the contact of vertical ones with those which are parallel to the bedding. The ore was deposited as sulphide, and the mineral-bearing solutions evidently circulated along the channels which the faults and fractures offered. The epoch of ore deposition was short compared with that of the faulting, for we know that the faulting has been continuous, and can trace several distinct systems which have developed successively from the earliest period to the present. The first-formed systems are ore bearing, showing that they existed at the time of the presence of the mineral-bearing solutions. The later systems are, however, barren, and evidently no ore-bearing waters have circulated along them. This refers, of course, to the main or primary mineralization. There is always going on a secondary deposition of ore, due to the rearrangement of the first-deposited minerals, but this process is comparatively unimportant.

Fault systems.—After the formation of the first or north-south system of faults, which we may call the Aspen Mountain system, the next in point of age was the Della system. These faults are not numerous, and have no

great throw. They have an east-west trend and a dip to the south of about 30 degrees. The phenomena along these faults tend to show that they originated previous to the ore deposition, but continued after it, so that they belong in a later system than do the Aspen Mountain faults, which appear to have been almost entirely developed before the cessation of this process. According to Mr. D. W. Brunton, who has made a careful study of the Della faults, about three-fourths of the movement occurred since the ore deposition.

Next in the order of development of faults seems to have come the Tourtelotte Park system, which has a north-south trend and a nearly vertical dip. The faults of this system have their greatest throw in Tourtelotte Park and diminish toward the north and to the south. They have apparently been developed entirely since the close of the ore deposition, and are therefore barren.

Belonging to a slightly later date than the north-south Tourtelotte Park system are the east-west faults of Tourtelotte Park, which constitute the Butte system. This system, although probably it originated at about the same time as the north-south Tourtelotte Park faults, has apparently had its greatest activity at a slightly later period, and some of its faults have developed entirely in post-Glacial time. This is the most recent of all the fault systems, and the disturbance is still going on. Most of the other faults in the systems previously enumerated are still moving slightly, but not to such great extent as the Butte system. The universal motion shows, however, that the Tourtelotte Park uplift is still slowly progressing.

Cause of uplift.—The most interesting feature in the structure of this district is the local uplift which has caused the formation of numerous faults, and, indirectly, of the ore deposits, for along these faults the ore-bearing solutions have circulated, and there they have deposited their load. This uplift is purely local and has no apparent reference to the structure in the surrounding rocks. It does not seem probable. therefore, that it has been formed by regional stress or by any lateral thrust, but is such as might be formed by a vertical push from below by some restricted force. The period at which its formation began was one of intense eruptive activity. Immediately previous the diorite-porphyry and quartz-porphyry were intruded into the sedimentary rocks. The diorite-porphyry has been shown to be probably an outlying sheet connected with the main dioritic mass of the Elk Mountains, while the quartz-porphyry has apparently

close genetic connection with the eruptive rocks of the Mosquito Range, on the opposite side of the Sawatch. As already described, there have been found at Aspen dikes of porphyry which come directly across the sedimentary formations and connect with the overlying sheet. These dikes were found in the Bonnybel, Smuggler, and Park Regent mines. In the first named of these mines the dike sends out thin and limited sheets into the Carboniferous dolomite before reaching the horizon at which the main sheet spreads out. It has been concluded, therefore, that the porphyry at Aspen came up directly from below and was derived from some larger reservoir. Throughout the whole of this western mountain region igneous rocks are common as sheets, as lenticular bodies or laccoliths, and even as cylindrical pipes or "plutonic plugs," as described by Russell.[1] The same quartz-porphyry, or a rock very closely related, forms laccoliths on the Mosquito Range, and thick sheets, such as are seen at Leadville. A possible explanation of this Tourtelotte Park uplift would be that igneous rocks, probably derived from the same reservoir as the previously intruded porphyry, accumulated in a restricted area; that upward propulsion of this rock elevated the overlying rigid formations, and that this uplift caused the fracturing and faulting. We may conceive that if this upward tendency of the molten rock beneath had been actively continued, the rock would have forced its way to the surface, and what is now the limited, faulted, uplifted dome would have become the neck of a volcano. Actually, however, no rock was erupted, although, as previously noted, there is a late eruption of basalt along the Castle Creek fault a few miles farther northwest, near Woody Station.

Rate of faulting.—One of the most striking things in the geology of Aspen is the evidence of great activity in the deformation of the rocks, both in the past and in the present. This evidence offers, perhaps, an opportunity for estimating the rate of movement along these active faults. Mr. D. W. Brunton, in a letter written to the author, makes the following interesting observations concerning recent fault movements:

That the movement along the fault planes is now going on is plainly proved in a great many ways. Survey monuments, which have been located by different engineers with exactitude, are now in some instances 4 and 5 feet from the position they occupied ten years ago. The upper portion of many shafts in the camp has been moved entirely across the lower portion, in some instances shutting off com-

[1] Jour. Geol., Vol. IV, pp. 25, 189.

munication with the bottom end of the shaft, and in others, where mining has been going on steadily, the two disjointed ends are connected by a short incline. Where the Della S. fault passes up through the Park Regent there is one drift along the line of this fault. The square sets with which this drift is timbered assume the form of rhomboids so rapidly that the superintendent, in order to avoid trouble with the track, laid the rails on short ties instead of spiking them to the square-set sills, so that the track could be kept up level without any reference to the timber sets inclosing the drift. I inclose a little sketch [fig. 6] showing the timbers as they were originally placed and the position of the timbers after they have been in position from one to two years.

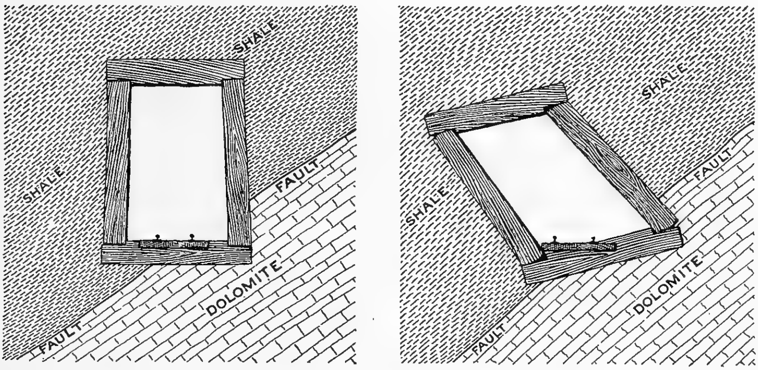


FIG. 6.—Deformation of drift in Della S. mine by movement along fault.

In the Butte fault in Tourtelotte Park there seems to have been a movement in post-Glacial time of at least 400 feet. If, then, we can arrive at any approximation of the period which has elapsed since the disappearance of the ice sheet, we may have some measure of the recent rate of faulting. Warren Upham,[1] after correlating the various estimates as to the period which has elapsed since the disappearance of the continental ice sheet from the northern half of North America, comes to the conclusion that it may safely be estimated at between six thousand and ten thousand years. Glaciation in the Rocky Mountains has been considered somewhat more recent, but the country around Aspen bears evidence of profound glacial activity in no very recent times. The whole of the district mapped has been glaciated, and the ice sheet must have been of enormous thickness, since it filled up the Roaring Fork Valley and overrode Smuggler, Aspen,

[1] Pop. Sci. Monthly, Dec., 1893, p. 161.

and Red mountains. After the disappearance of this vast ice sheet there was a comparatively quiet period, during which erosion went on rapidly and the river valleys were filled with local glaciers, which formed distinct and later moraines. In many cases the débris of this earlier ice sheet has been stripped by erosion from the mountain sides and is found only on top, as in the case of Red Mountain. In other places it has probably been entirely removed. This amount of erosion, even taking into consideration the activity with which material was removed in this mountainous region, indicates that the main ice sheet disappeared at no very recent period. We may therefore assume that the minimum figure given by Upham represents the period of post-Glacial time in the Rocky Mountains, namely, six thousand years. If the Butte fault has moved 400 feet in that time this would make a rate of about 1 foot in fifteen years. This rate is the maximum, so far as is actually known, of present movement, and in estimating the rate of the faulting as a whole other considerations come in. At the beginning of the uplift and faulting there was a great load of overlying rocks in the uplifted area; and this load rendered faulting slower and more difficult. The load amounted to at least 15,000 feet of strata on the east side of the fault at Tourtelotte Park. These 15,000 feet are all exposed in the district just west of the fault, but on the east side are stripped away by erosion, which has usually kept pace with the uplifting and faulting, though often lagging behind. The disturbance which began under this heavy load consisted in the upbending of the strata, with few fractures, but along these few the displacement was important. With the stripping of the strata there developed more numerous faults, which, however, had in general slighter movement. Thus the intersecting faults in Tourtelotte Park are numerous and complicated, but are all comparatively late in origin. So the rate of the fault movement at the present day, which has been approximated at a maximum of 1 foot in fifteen years, is probably the maximum for the whole period of deformation. It has been roughly estimated that about two-thirds of the faults originated since the ore deposition, but the premineral faults are characteristically heavier, and from the considerations above stated it seems probable that the ore deposition lasted through two-thirds or even more of the time from the beginning of the uplift to the present day. Thus the ore began to form under not more than 15,000 feet of sediments and probably ceased when covered with 5,000 feet or less.

CHAPTER III.

DESCRIPTION OF MINES AND PRODUCTIVE LOCALITIES.

In the preceding chapter the general geology of the Aspen mining district has been discussed. Within this district are certain segregated areas to which the actual ore production has been almost entirely confined, and where most of the mines are located. In the most important of these localities the geology has been more accurately determined, thanks to the numerous opportunities offered in mine workings, and special maps of these localities have been made on the 300-foot scale.

ASPEN MOUNTAIN.

One of the areas of greatest production is the north slope of Aspen Mountain, between Tourtelotte Park and the town of Aspen. In the eastern limb of the synclinal fold of Aspen Mountain there is a continuous series of underground workings, reaching connectedly from the level of the town up to the top of the mountain. In this particular region the Contact fault between the blue limestone and the dolomite has been considered the most favorable place for exploration, and hence this fault, or "contact," as it is called, has its outcrop marked the whole distance up the hill by a continuous line of tunnels. From this outcrop the workings have often gone downward along the dip to a great depth, as is especially the case in the Aspen mine.

Bonnybel mine and Visino tunnel. (See Pl. XL, *A*).—This mine is situated in a small downfaulted block which is bounded on the east by the Bonnybel fault and on the west by the Chloride fault. These faults dip to the southwest and converge in dip and in trend, so that they probably unite in depth and merge into the Silver fault. The downfaulted block is marked on the surface partly by the Parting Quartzite beds. The course of these beds seems to be comparatively normal from Spar Gulch southward nearly to the Bonnybel mine, but here the outcrop is faulted down the hill for

some little distance. A little farther on, however, on the south side of the downfaulted block, the quartzite resumes its original position. Farther up the hill this block is characterized by the Weber shale which lies in it, between the blue limestone on the north and that on the south. The block between the two main faults is not simple, but is cut by very many slips, which are in a general way parallel to those that bound the block, so that actually the block is a sort of downthrust shear-zone in which the rock is cut into thin slices. Besides these parallel faults there are also minor slips running in all directions. A peculiar feature in the structure is the absence of the blue limestone in the Bonnybel mine, for here porphyry and Weber shale directly overlie the Leadville dolomite. That this dolomite probably belongs to the permanent and original bed which forms the lower portion of the Leadville horizon is indicated by its estimated thickness, which is that usually found in the Leadville dolomite. There is evidently, therefore, a fault which here locally cuts out the blue limestone and brings the Weber formation down upon the dolomite below. This is the condition of affairs in the northern district, from the bottom of the Roaring Fork Valley to Lenado, and it results from the action of the Silver fault. Throughout Aspen Mountain and Tourtelotte Park, however, there is usually blue limestone between the dolomite and the shale. In the outcropping cliff on either side of the downfaulted block in which the Bonnybel mine is situated there is continually shown the usual Contact fault overlain by the blue limestone, and thus it is in this block alone that the limestone is missing. The fault, therefore, can be only a local one.

Another unusual and especially interesting feature of the mine is the occurrence of porphyry in the dolomite in the form of a large crosscutting dike and of small interbedded sheets. The dike seems to be nearly vertical as exposed at many points in the workings, being present in the rock as far down as explorations have gone, or nearly to the horizon of the Parting Quartzite. From this dike there run off one or two interbedded sheets, perhaps more. These sheets are cut in the main workings, and have always altered the dolomite along their contact for several feet to a coarsely crystalline, nearly white marble. This is the only place in the district where porphyry sheets have been found at a horizon lower than the Weber. In the dolomite, however, these sheets are small and thin, and no important thickness is found till the horizon of the Weber shales is reached, at which

horizon the porphyry has spread out more or less irregularly, and includes fragments of the shale.

Nearly the whole of the dolomite in this downfaulted block has been highly mineralized, so as to form ore of greater or less richness. The richest ore, however, lies in irregular shoots which are parallel with the main faults, dipping steeply to the southwest and having a northwest trend. These rich shoots lie very close together, as seen in the Visino workings, and from them an immense amount of ore has been taken out. At the surface, in the middle of the block, the ore was first discovered in outcrop, and here $110,000 worth was taken from the great Bonnybel open stope, without timbering. This stope seems to occur between two parallel faults of the main system. The richest ore is in the southwest side of the block, where the faulting seems to have been greatest. In the Bonnybel fault, which bounds the block on the east, only one pocket of ore has thus far been found, that in the Forest tunnel.

The occurrence of the ore in the Bonnybel is noteworthy among that of the other mines of the district, in that nowhere else has the rock been mineralized to such a degree. In other mines there are small bodies of ore far richer than that in the Bonnybel, but here not only has the whole rock been transformed into low-grade ore, but the mineralization is in distinct steeply dipping shoots which cut across the formations. The explorations are now not far above the Parting Quartzite and there is still rich ore in sight, so that it is hard to tell how much farther down the ore deposits will extend.

The ore itself is a mineralized, broken dolomite containing much barite, and so far is all oxidized. A little native silver has been found.

Durant mine.—The Durant is connected with the Bonnybel by the Visino incline, which in descending runs to the westward with the dip of the rocks. This mine is situated on the east limb of the Aspen Mountain syncline and near the summit of the Tourtelotte Park uplift, where the steep north face of this uplift begins to flatten in Tourtelotte Park. As the result of this position there occur in the mine many small fractures and cross faults, which complicate the structure very much and render scientific mining absolutely necessary. The eastern limb of the syncline becomes very steep a little below the surface, turning down so as to become vertical, and even locally overturning so as to dip to the east. After this sudden

steepening the beds recover and assume a flatter westerly dip, which suddenly changes to a very gentle dip in the bottom of the syncline. Near the point where the dip changes there is developed the Aspen fault, vertical, and with only a slight throw, which is down on the eastern side. The workings of the Durant mine show this structure well, the whole of it having been accurately demonstrated from the surface to the bottom of the syncline. Most of the workings lie in a comparatively narrow zone between the vertical Aspen fault and the Contact fault, which is here turned up with the beds so as also to be vertical and for a long distance parallel with the Aspen fault. West of the Aspen fault there is developed in the workings another fault belonging to the same system, namely, the Schiller. There are many smaller faults parallel to these greater ones, and also many complicated cross slips and intermittent fractures. Many of these occur between the Aspen and the Contact faults. They have been admirably and carefully worked out by Mr. Rohlfing, the superintendent of the mine, but are not of sufficient importance to be dwelt upon in this general summary. The Silver fault is also cut in the southern part of the workings, but has nowhere been very greatly explored.

The ore has been found chiefly in the narrow vertical zone between the Aspen and Contact faults. On account of the northerly pitch of the Aspen Mountain syncline, the point where the steep eastern limb of the syncline flattens out to form the bottom of the fold becomes gradually deeper toward the north; and for this reason the narrow vertical zone which is highly productive in the Durant mine extends still farther downward in the Aspen, where it has been followed nearly 1,500 feet from the surface before the bottom of the syncline was reached. In the Durant ore has formed in immense bodies, especially along the various faults and fractures. Of these there are many, and those which have a slight throw or no throw at all are apparently as important in forming ore as are the greater ones, showing that the only effect which a fault has in the formation of ore is to furnish a channel through which the ore-bearing solutions may circulate. The ore is nearly always found in the dolomite at the intersection of one or more of these faults with the Contact fault. In such cases ore may occur above the Contact fault in the blue limestone, when it is generally surrounded by an envelope of dolomite, the dolomite in turn being surrounded by limestone. In one case lead ore was found directly in the

limestone with no dolomite envelope, but on analysis the ore was found to contain 5 or 10 per cent of magnesia, while the limestone around it contained none. These facts indicate that dolomization was, in part at least, attendant upon the mineralization; that the ore deposition took place from solutions circulating along fault fractures, and that they deposited their contents by preference at the contact of two or more of these fractures.

The ore in the Durant varies greatly, both in composition and in quality. There has been a large amount of oxidized ore taken out, but now a great portion of it is sulphide, although most of the existing stopes show more or less transition between the sulphide and oxidized conditions. As is the case throughout a large part of the camp, the ore is chiefly an argentiferous galena, which has replaced the dolomite and limestone to a greater or less extent. There is also considerable zinc sulphide and carbonate, and in some of the ore the silver probably occurs in large part as argentite. On Pl. XL, *B*, a cross section through the Durant and down the "Electric winze" of the Aspen mine is given, showing the typical structure of the Durant and the Aspen mines and the occurrence of the ore bodies. The ore figured on this section is that which has actually been taken out, and the narrow zone to which it is confined is well shown. There are, however, evidences of ore in other parts of the rock, particularly in the faulted region in the right-hand or western part of the section.

Aspen mine.—The Aspen shaft passes through a small quantity of porphyry and Weber shale and through the blue limestone to the Contact fault, along which most of the workings are located. The general structure shown in the mine is a continuation of that in the Durant. Throughout the whole runs the Aspen fault, very nearly vertical and with a north-south trend. A short distance east of the Aspen fault, between the blue limestone and the dolomite, is the Contact fault. This fault has slickensided walls and often a triturated zone, showing its nature. In its main course it has a north-south trend, nearly parallel with the Aspen fault, but approaching it slightly toward the south, so that finally they meet. From the sixth level down the dip of the Contact fault is reversed and becomes very steeply east. At the sixth level it is about 85 degrees, but farther down it approaches 70 degrees. At a certain point, which varies, being deeper in the Aspen mine than anywhere else,

the Contact fault flattens out and runs into the Aspen fault. On the west side of this it becomes shallower, with a more northerly dip and a general east-west strike. The point at which the Contact fault runs into the Aspen fault naturally becomes lower toward the north, so that in the successive levels we find this point constantly advancing.

Besides the Aspen and the Contact faults there are, as in the Durant, a number of minor faults and cross fractures, which seem to be dependent upon and synchronous in origin with these greater faults. They are nonpersistent, often continuing but a short distance before running into one of the larger faults and disappearing. Along these faults, especially at their intersection, the ore is formed in immense and rich bodies. On account of the vertical position of the ore-producing zone, the mineral has been almost continuously stoped out down to nearly 1,500 feet below the surface, and it is claimed that for this reason the Aspen mine has been by far the greatest producer, in proportion to its surface acreage, among the mines of Aspen.

Owing to their parallelism with the Contact fault, the ore shoots have a general dip to the east. The ore occurs indiscriminately in limestone or in dolomite, or in the Contact fault between the two, since immense stopes have been excavated in dense dolomite, while in other cases they lie entirely inclosed in blue limestone. But, as seen in the cross section, the ore bodies are, in a general way, confined to the fractured and sheeted zone where the beds have been overturned against the Aspen fault.

The ore is practically the same as in the Durant mine, consisting in the lower levels principally of argentiferous galena with some blende. Most of it contains some barite. In the upper levels the ore has been oxidized, so that the metals occur chiefly in the form of carbonates and oxides. A peculiarly interesting type of ore was noted on the third level, near the shaft. This ore is to the eye a pure and apparently unaltered blue limestone, being hard and fresh. It contains no lead, and the silver is said to exist in small black specks of sulphide. This ore is said to be high grade, running 200 ounces or more. On both sides of it there is barren blue limestone. In the Forest stopes, at about the second level, the ore also occurs with blue limestone on both sides, far from the solid dolomite, but in this latter case the ore is dolomized or has dolomite as a gangue, the dolomite being derived from the local alteration of limestone; and as this

A. M. AND S. MINE, NO. 6 STOPE

association of ore with dolomite is almost invariable, its occurrence in an unaltered blue limestone is extraordinary.

Schiller mine.—The Schiller workings lie just west of the Durant, and the ore-bearing horizon occurs somewhat lower down. The mine is reached by the Schiller shaft, and also by the Schiller incline, which runs from the Durant workings. The Schiller shaft passes through about 390 feet of porphyry and 190 feet of broken porphyry and shale to the bottom, which is in the Silver fault. From the shaft an incline runs down through the Silver fault, across the blue limestone, to the Contact fault. The Schiller fault runs in dolomite from the 200-foot level of the Durant down to the level at the bottom of the Schiller workings. This level runs off to the south in dolomite to the breast, where a bed of quartz and black dolomite, with a fine material strongly resembling the Parting Quartzite, is encountered. The Schiller fault runs through the foot of the incline from the Durant in a nearly vertical line with a north-south trend. There are one or two parallel slips near the Schiller fault, evidenced by slickensides and fissures filled with fine clay, and the Contact slip is shown in the lower workings. Along these several faults ore has formed and has been stoped out at intervals.

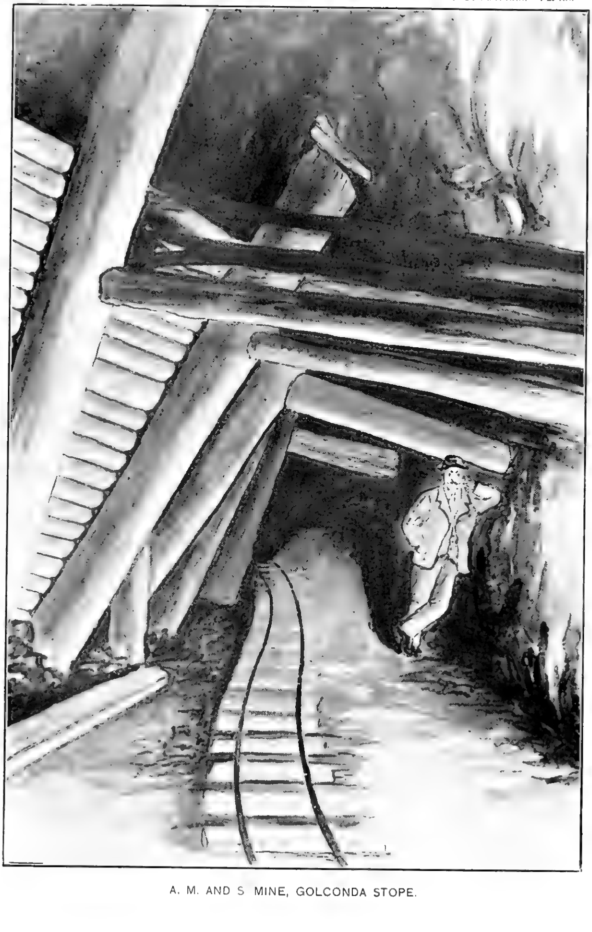
The Aspen Mining and Smelting Company mine.—This mine, currently called the A. M. and S., is reached by the Veteran tunnel, which cuts through the glacial drift to a point close to the Franklin shaft, where it enters Weber shale. It soon after crosses a thin bed of blue limestone and enters the Contact fault. The formations in the A. M. and S. are the same as in the Aspen and the Durant, but the great local steepening and overturning of the beds noted in the mines just described is here absent. There is, it is true, a slight steepening, but, so far as exposed, the dip is fairly uniform from the outcrop down to the bottom of the workings, being about 35 or 40 degrees. The Silver fault is shown in the tunnel, where the zone of shale above the blue limestone is very much crushed, and also at several other places in the lower workings. In this mine the Silver fault cuts down across the formations so that the blue limestone becomes quite thin. The Contact fault between the blue limestone and the underlying dolomite is well shown, the brecciated zone along it being often thick and conspicuous. A feature of the Contact fault which is not noted in the most of Aspen Mountain is the presence of bowlders of porphyry in the breccia, these

bowlders being often of large size and very conspicuous in the black matrix. This seems to be a result of the thinning of the blue limestone and the convergence of the Silver and the Contact faults. There are many large and interesting caves in the blue limestone just above the Contact fault in this mine, which mostly seem to have been formed since the ore deposition.

The ore occurs along the Contact fault, but chiefly along certain parallel zones or shoots in this fault. These shoots, which are three or four in number, have a northeast trend and correspond to a system of fractures and slight faults which are found in the rocks in this vicinity and which are cut in the Durant tunnel. The ore is an altered limestone, containing much galena and often a great deal of barite. Pls. XX and XXI are from photographs of stopes in the A. M. and S. mine.

Durant tunnel.—The Durant tunnel runs in from the bottom of Aspen Mountain to the deep mines, thus affording convenient means of transporting ore and of drainage. It starts in the Leadville dolomite very close to the Parting Quartzite, and soon encounters a series of northeast faults and fractures, which are in general vertical, although some dip northwest and others southeast. Along these faults are triturated zones and open water-courses. There are many of these faults, and their general effect is to shift the formations very slightly back to the east on the south side. The strike of the formations at the north is slightly more easterly than the general trend of the tunnel, so that the tunnel tends to go down in the series, but the effect of the faults is to keep it along nearly the same horizon, near the Parting Quartzite, for the first 1,000 or 1,500 feet. Then comes a marked steepening of dip, as has already been noted in the Aspen and Durant mines, so that the rocks become nearly vertical. The strike also swings round more to the north and the tunnel goes steadily up in the series till it strikes the Contact fault.

Homestake shaft.—The Homestake shaft went through 240 feet of drift, 265 feet of porphyry, and 115 feet of shale to the Silver fault; then through 225 feet of blue limestone to the Contact fault. These thicknesses, however, are taken on a very steep dip, so that the actual thickness of blue limestone is not over 40 or 50 feet. This is also its thickness in the northern part of the A. M. and S. mine. Close to the Homestake shaft is situated the mouth of the Enterprise tunnel, which runs from this point east to the Contact fault.



A. M. AND S MINE, GOLCONDA STOPE.

Enterprise tunnel.—The Enterprise tunnel runs in drift to the blue limestone, and through this to the Contact fault. A drift runs from this point northeast and southwest on the Contact fault, which shows slickensiding, brecciation, and watercourses filled with mud. These workings have developed some ore along the Contact fault, in shoots which probably belong to the same system as those of the A. M. and S. Ore is also found along the same shoots in the Little Nell tunnel and the Thousand-and-one incline.

Argentum-Juniata mine.—In this mine the formations are the same as in the A. M. and S., but they do not outcrop, since they are entirely beneath Roaring Fork Valley and are deeply covered with drift. This mine affords one of the most favorable means for determining the structure which lies under the river valley and which is hidden by the glacial material, and from its workings, and those of the Mollie Gibson on the other side of the valley, it appears that there is no great complication in the space between Aspen and Smuggler mountains. The Argentum-Juniata workings are run on the Contact fault between the blue limestone and the dolomite, which, with the other formations, have a steep but comparatively uniform dip. There is some slight faulting shown in the mine, but none which has any very heavy displacement, if we exclude the Silver fault. This fault is exposed between the shale and the blue limestone at one or two points by cross drifts running west from the Contact fault, and is characterized by a thick breccia of porphyry, shale, and limestone, and by open fissures and watercourses in the limestone, parallel to the main fault. Besides the Silver and the Contact faults the disturbance consists mostly of a series of parallel fractures, which have some slight displacement. These strike northwest and have a steep southwest dip. Along some of these fractures much water pours into the mine. An interesting feature is the alteration of the limestone and dolomite along some of the zones of fracture to a soft, black material, which so closely resembles the softened Weber shale that the two can not easily be distinguished.

The ore has been found chiefly along the Contact fault, but irregularly distributed. It is not yet determined whether the system of northwest fractures has any reference to the localization of the ore deposits. The ore is an alteration of limestone or dolomite, is generally stained brown by iron oxide, and carries considerable barite.

Princess Louise and Hidden Treasure.—The Princess Louise shaft is situated in Spar Gulch, near its junction with Copper Gulch, and the Hidden Treasure is near by, in Copper Gulch. Both these workings are now abandoned. The Princess Louise started in the Silurian dolomite and went down into the Cambrian quartzite. It is said that a small quantity of ore was mined in the Cambrian quartzite at a distance of about 60 feet below the contact with the Silurian. The ore carried silver, and occurred along nearly vertical east-west fractures in the quartzite. The chief interest which pertains to this shaft is the fact that ore has occurred here in the Cambrian quartzite, although in small quantity.

WEST SIDE OF ASPEN MOUNTAIN.

On the west side of the Aspen Mountain syncline there are a number of workings, chiefly tunnels, some of which are very extensive. These usually find some ore along the vertical north-south faults, especially in the chief ones—the Saddle Rock and the Pride.

New York tunnel.—The New York tunnel is one of the longest of these workings. It runs south into the hill, so that it cuts across the formations and reveals successively lower strata. The first 500 feet is in the shale which overlies the porphyry, the second 500 in the porphyry itself, and then about 100 feet in the shale which underlies the porphyry. At this point the Cambrian quartzite is reached by crossing the Saddle Rock fault, and is continued in for about 285 feet to the granite below.

Great Western tunnel.—The Great Western tunnel starts in the hillside above the New York. It passes through a few feet of the shale which overlies the porphyry, and then continues in porphyry to near the end, where it cuts a little shale and crosses the Saddle Rock fault into the granite.

Pioneer tunnel.—The Pioneer tunnel starts on the hillside on about the same level as the New York tunnel, but farther to the west, and like it, runs south into the hill. After passing through a slight thickness of glacial drift, it goes through 330 feet of shale, 50 feet of porphyry, and 230 feet of shale, then crosses into the blue limestone, of which there is about 75 feet, to the Saddle Rock fault, and crosses this fault into granite.

Galena tunnel.—The Galena tunnel starts in dolomite in the block between the Saddle Rock and the Pride faults, and runs west, slightly

south, for 250 feet to the contact between dolomite and granite caused by the Pride fault.

Late Acquisition mine. (See Pl. XL, *C*).—The Late Acquisition shaft is 125 feet deep and is entirely in dolomite, which is probably Carboniferous. In this shaft there are four levels, of which the upper two are short and extend in a westerly direction. The third level, which runs to the east, cuts the Parting Quartzite 50 feet from the shaft. On this level a considerable amount of medium-grade lead ore has been found along the Saddle Rock fault and along parallel slips in the dolomite. One hundred feet below the third level is the fourth or tunnel level, which runs due north and south on a fault plane which is marked by a perpendicular, highly polished and striated wall of dolomite on the west side and by blue limestone on the east. This is not the main Saddle Rock fault, but a parallel slip about 50 feet west of the main one. The rock along this fault is mineralized, containing considerable lead and zinc sulphide, which has replaced the dolomite.

The ore throughout this mine has the general characteristics of the West Aspen Mountain ores, as shown in the Pride of Aspen mine. It is a high-grade lead ore with only a small amount of silver. There is almost no barite, and tons of the ore often average less than 1 per cent of baryta.

ASPEN MOUNTAIN MINING MAP.

The Aspen Mountain map (Atlas Sheet XXV) includes the productive mines of Aspen Mountain, except those near the point of West Aspen Mountain. Through the center of the district runs the outcrop of the highly metalliferous zone which is continuous from the Argentum-Juniata up to the Durant. In the bottom of the Aspen Mountain syncline little mining has yet been done, although it offers a favorable field for exploration, while on the west side of the syncline are some long tunnels.

Besides the structure already shown on the smaller-scale map, some additional details appear on the Aspen Mountain map. The Contact fault between the limestone and dolomite of the Leadville formation is represented, and the distinction between limestone and dolomite is indicated by different coloring. An east-west fault which crosses Spar Gulch at the southern edge of the mapped area and which represents a system of nearly vertical northeast faults, with usually very slight throw, is also shown.

This has a slight downthrow on the north side. It is probably only a local cross fault, running diagonally between north-south faults of the Ontario or Tourtelotte Park system and the Silver fault. The main systems of faults are shown on this map as on the larger one. West of the Silver fault there come in the Schiller and the Sarah Jane, and farther west is shown a portion of the Saddle Rock, where it flattens and locally advances in outcrop toward the east.

Section A.—The eastern end of Section A, Atlas Sheet XXVI, is near the northern point of East Aspen Mountain, in granite. To the west the upturned beds of Cambrian and Silurian are successively crossed, then the Parting Quartzite and the Leadville dolomite. There are represented in this section the two faults into which the several breaks of the Ontario system have resolved themselves on East Aspen Mountain. Their position is not certain, but is approximately as shown, both having probably a slight downthrow on the west side. The blue limestone above the Contact fault actually outcrops, and above this comes the Silver fault, separating the porphyry from the blue limestone, with generally some little shale between. The Aspen fault is not well marked, but is shown as splitting off from the Silver fault and assuming a steeper dip at the point where the east limb of the syncline flattens to form its bottom, while the Silver fault continues across the syncline with the beds. The section cuts through the Homestake deep shaft and shows the large amount of drift which that shaft has traversed. This mound of drift is very conspicuous in the field, forming a low hill at the bottom of Vallejo Gulch. To one who is familiar with the landslides of the Rocky Mountains it is evident that this hill originated in some such catastrophe, and that Vallejo Gulch was cut through the material which formed this mound. The landslide took place in post-Glacial time, since the débris juts out into the valley, covering up the glacial materials.

West of the Homestake shaft there are few opportunities for determining the underlying rocks, and the structure is inferred from data gathered farther south.

Section B.—On the eastern side of Section B the beds flatten, indicating a tendency toward anticlinal structure. The two faults of the Ontario system are cut at a point farther south than in Section A. Their throw, therefore, is greater. The flat dip on the top of the mountain steepens toward

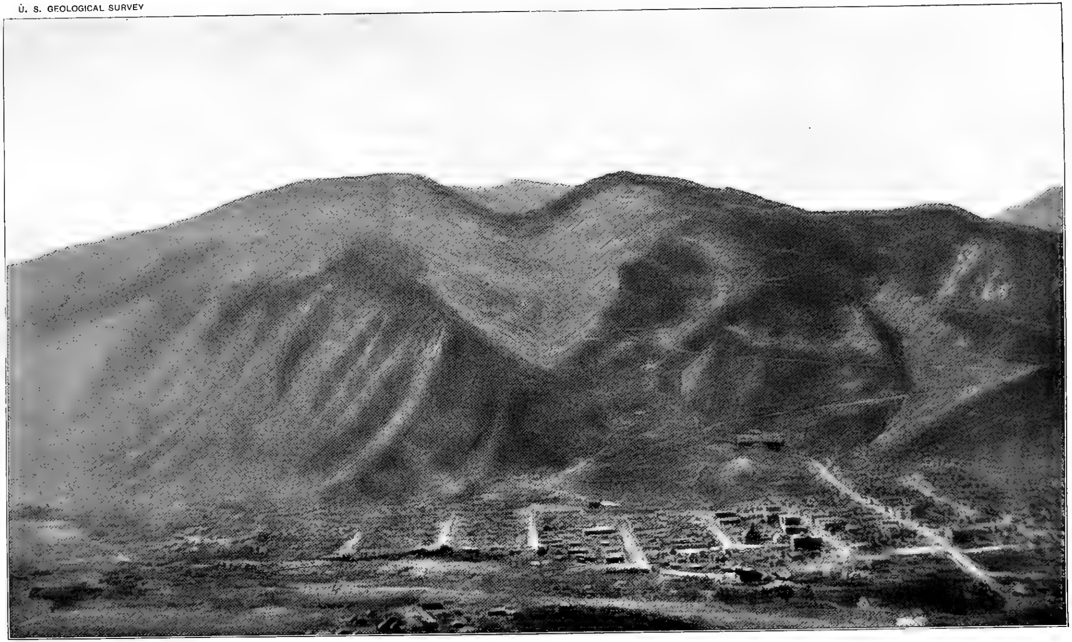
the west and then flattens again on nearing the bottom of the syncline. The slight thickness of blue limestone shown between the Silver and Contact faults has been well proved by mine workings. On the bottom of the section, below the Franklin shaft, the Aspen fault is represented as splitting off from the Silver fault, as in Section A. West of the Franklin shaft the bottom of the syncline is passed through.

Section C.—The eastern end of Section C shows the tendency to anticlinal structure somewhat more strongly than Section B. Just west of the eastern end a cross fault of the Tourtelotte Park later system is cut. The beds have a comparatively gentle dip, almost identical with the slope of the hill. The section runs nearly parallel to the Bonnybel and Chloride faults, but, being vertical, while these faults have a southwest dip, it intersects them. The intersection with the Bonnybel is nearly horizontal, while that with the Chloride, which has a slightly differing trend, is more steeply inclined, and the two faults come together and run into the Aspen fault in the Durant mine. The section cuts through the Bonnybel mine, the Visino incline, and the Durant workings, where many of the data have been obtained. The steep easterly dipping fault not far west of Spar Gulch is one which is found near the mouth of the Visino tunnel, and in the Bonnybel mine a fault has removed the blue limestone from the small downthrust block between the Bonnybel and the Chloride faults. A vertical dike of porphyry, sending out small sheets, is also found in the Bonnybel and has been followed nearly down to the Parting Quartzite. This is shown continuing downward indefinitely and faulted by the Bonnybel fault, which seems in the mine to be of later date than the porphyry intrusion. The nature of the Aspen fault, as shown, has been well developed in its lower course by mine workings. It is represented as running into the Silver fault above. Between the Aspen fault and the next important fault to the west (the Schiller) there are a large number of minor breaks. Two of the chief of these, which are called by the mine managers the Schiller No. 2 and the Conomara, are known to be nonpersistent and are represented as uniting and dying out in the porphyry above. The section cuts the block between the Schiller and the Sarah Jane faults just north of the outcrop of the contact of porphyry with the overlying shales.

Section D.—Section D, Atlas Sheet XXIX, is at right angles to Sections A, B, and C, Atlas Sheet XXVI, which have been drawn at right angles to

the general strike of the beds on East Aspen Mountain and throughout the rest of the district in general. They are not, however, at right angles to the strike of the beds in the main part of the Aspen Mountain area, for here the strike is variable, being altered from the usual direction by the influence of the Tourtelotte Park dome and by the Aspen Mountain syncline, which lies on the north face of the dome. Section D cuts across the center of the map and shows the westerly dipping strata on the east side of the syncline. It also cuts through the Tourtelotte Park dome, so that the formations as shown are not horizontal, but cross the uplift. In a section like this, which cuts the formations obliquely, the thicknesses are greatly exaggerated, and that of each bed varies with the changing local dips, the thickness being apparently greater as the beds become steeper. At the northern end is a thick covering of glacial drift, partly rearranged by water action, which covers the bed rock in the Roaring Fork Valley. The section follows continuously the line of workings which run along the Contact fault on Aspen Mountain from top to bottom, reaching from the Argentum-Juniata up to the Durant. Above the Durant the flattening of the beds indicates the appearance of a slightly different structure, and throughout Tourtelotte Park the workings are not so large nor so continuous. The Silver fault is also continuously shown in the section, except in the northern part, where it runs into the glacial drift. Near the top of the hill are the Chloride and the Bonnybel faults, or, rather, the sheared wedge which these faults represent. These are shown near their junction with the Silver fault, and are very close together, forming practically a single fault. Beneath the drift on the north the two faults of the Ontario system are represented with very slight throw, dying out against the Silver fault.

Pl. XXII is a general view of Aspen Mountain from the slopes of Red Mountain, looking south, showing the town of Aspen below. The prominent squat hill at the foot of Vallejo Gulch which appears in Section A, Atlas Sheet XXVI, consisting entirely of loose material which the Homestake deep shaft has penetrated, is shown to the right of the center of the picture. At the right is the edge of West Aspen Mountain and on the left is East Aspen Mountain. In the center is Spar Gulch, with Copper Gulch running into it, and near the top of the mountain is Tourtelotte Park.



ASPEN MOUNTAIN, FROM RED MOUNTAIN.

WEST ASPEN MOUNTAIN.

Pride of Aspen mine. (See Pl. XLI, *A*.)—The Pride of Aspen workings consist chiefly of two tunnels and a shaft. The shaft is 400 feet deep, having passed through 250 feet of glacial drift, 190 feet of Weber shales, and 60 feet of the gray limestone which forms the base of the Maroon formation. The position of the Weber above the Maroon gray limestone in the shaft, taken together with the dips of the formations in the two levels, shows that the strata have been locally overturned. There are two levels from the shaft, one at 200 feet and one at 400 feet. The upper one runs west a short distance in Weber shales; the lower one starts in the Maroon gray limestone and runs west in solid limestones and shales, which become soft as the drift advances westward toward the Pride fault. This fault is cut about 200 feet from the shaft, and on the other side the Cambrian quartzite is exposed. The upper tunnel runs south, and is for most of its length directly in the Pride fault. The Pride fault has a very steep easterly dip, so that the foot wall is dolomite and the hanging wall shale. The shale of the hanging wall is mixed with limestone and porphyry, sometimes brecciated, sometimes in large, solid bodies. The second tunnel, which is 90 feet below the other one, is in Weber limestone, and does not cross the fault, although it runs very close to it. In this locality there are many fractures, the chief set trending due east and west and dipping north at an angle of 40 degrees. These fractures stop at the Pride fault and correspond to the east-west breaks which are developed on the north end of West Aspen Mountain.

The ore in the Pride of Aspen is found in the immediate vicinity of the Pride fault. The known ore bodies all lie parallel to this fault and at varying distances from it, in the shale on the east side, and have probably developed along fractures which were formed at the same time as the main fault. Some of the ore seems to have a connection, also, with the east-west, northerly dipping faults and fractures. The owners of the property believe that one of these faults crosses the Pride fault, and that at the junction of the two their ore is situated. The continuation of the east-west faults to the east of the Pride is doubtful, and certainly has not been proved by the developments thus far. The ore is low grade in silver, and carries much lead and some zinc, with less than 1 per cent of baryta.

Red Spruce shaft.—The Red Spruce shaft is 90 feet deep on the Pride fault. It runs in ore all the way.

Aspen Mining and Drainage tunnel, including the Copperopolis.—This tunnel runs southwest for 1,000 feet. Through the first 850 feet it cuts a breccia, apparently of glacial origin, which at first is composed principally of bowlders of red sandstone and blue limestone belonging to the Maroon formation, but farther in chiefly of gray limestone. Beyond 600 feet the bowlders of limestone decrease in size and are replaced by huge masses of Weber shale and limestone which have been considerably distorted. At 475 feet from the mouth of the tunnel a drift runs to the west 175 feet and cuts porphyry. This porphyry is considered the foot wall of the vein, while the hanging wall, which lies next it to the east, is composed of brecciated shale, porphyry, and black limestone. Ore has been found continuously along this zone, being developed by workings carried north and south. It lies in irregular masses, comparatively close but not always parallel to the porphyry wall. It is generally continuous and from 2 to 10 feet in thickness. The metallic sulphides occur in spaces between fragments of limestone in the crushed and broken zone. This breccia evidently lies along a north-south fault, extremely close to and dependent upon the Pride fault. The actual Pride fault, however, is not shown in the workings.

Little Cloud tunnel.—The Little Cloud tunnel runs into the hill between the Pride of Aspen and A. M. and D. workings, and cuts the same fault that is shown in both these mines. From here it cuts a little farther west than does the A. M. and D. tunnel and exposes the main Pride fault with a west wall of blue limestone underlain by dolomite. The east wall is composed of very soft, compact shale and porphyry breccia. No ore has been taken from these workings.

Mary B. mine.—The Mary B. shaft is in shale and porphyry breccia and touches the gray limestone of the Maroon series. From the shaft a level which runs off south has struck a very heavy fault with a northeast trend, which separates the top of the Weber and the gray Maroon limestone on the northwest from the Silurian dolomite on the southeast. The junction of this fault with the Castle Creek fault is seen in the tunnel just under the old powder house in Castle Creek. Close to this fault there has been a slight overturning of the strata, as they were dragged along the fault plane. Along the fault, in the Mary B., bodies of workable ore have been discov-

ered. This ore is different from the other ores of the camp, being characterized by an abundance of coarsely crystalline iron pyrite, inclosed in soft black material, which appears to have been triturated. The pyrite was analyzed in the laboratory of the Survey and proved to be simply iron sulphide, containing also small amounts of arsenic, lead, copper, and zinc, a small amount of silver, and traces of cadmium, cobalt, and nickel. Assays of this ore were also made to determine whether the values were chiefly in the pyrite or in the inclosing black material. The two, being separated as well as possible, were separately assayed. The pyrite assayed 14 ounces in silver, while the black cement assayed 90 ounces. No gold was found by either of these assays.

Homestake shaft.—The Homestake shaft of West Aspen Mountain must be distinguished from the Homestake deep shaft farther to the east. The former lies on West Aspen Mountain, on the northwest side of the Mary B. fault. It is in the basal Maroon gray limestone, and in some of its workings the gray and red sandstones of the Maroon are cut. Near the end of the drift, to the southeast, a crosscut west encounters the Mary B. fault and crosses it into dolomite. The strike of the Mary B. fault at this contact is N. 50° E.

Baltic tunnel.—The Baltic tunnel starts on the east side of West Aspen Mountain and runs in a westerly direction to the Pride fault. It is 780 feet long and passes through 155 feet of glacial drift and other débris, then through mingled shale and porphyry to the fault plane at the breast. On the west side of the fault is granite.

TOURTELOTTE PARK.

There is no actual break between the Tourtelotte Park district and that of Aspen Mountain, since ore is found continuously from one to the other. Just south of the Durant mine, however, the steep northern face of the domelike uplift flattens toward the south, and with it the Aspen Mountain syncline becomes shallow. These changes become more marked farther south, especially the flattening of the syncline, so that the dip of the formations, and with them of the Silver and the Contact faults, along which are the chief ore-bearing localities, becomes much slighter than on Aspen Mountain. Most of the workings in Tourtelotte Park are, therefore, comparatively close to the surface. Ore is found continuously from Aspen

Mountain to near Castle Butte at the south side of the park. At this latter point the northerly pitch of the beds carries the upper formations, such as the shale, and finally the blue Leadville limestone, above the surface, and with them the Silver and the Contact faults. South of this point the country has been comparatively barren, and is not likely ever to be very productive, with certain exceptions, such as in localities along the Castle Creek or its dependent faults, where there appears to have been great mineralization.

Bay State shaft.—The Bay State shaft lies close to the northern border of the district shown on the Tourtelotte Park mining map. The workings are in the blue Leadville limestone and in the dolomite of the same formation, exposing the Contact fault. This fault carries some ore, but no very important body. There has been some cross faulting in the mine, by which the Contact fault has been shifted about.

Ruby mine.—The Ruby mine is near the Bay State, and shows practically the same conditions. The shaft, which is 385 feet deep, starts in shale, crosses the Silver fault, and proceeds downward through the blue limestone across the Contact fault into the dolomite. There has been a great deal of faulting in this mine, which has shifted the formations considerably, but the faults do not seem to be very heavy or persistent. East of the shaft the general effect seems to have been to thrust the formations down slightly on the east side. There are two sets of fractures in the mine corresponding with the two sets of slight faults, one of which runs north and south, and the other east and west; and, so far as can be judged from the somewhat meager evidence, the east-west faults antedate the north-south ones. Both of these fracture systems seem to have influenced the deposition of ore, and some valuable bodies have been discovered along them. Most of the ore, however, occurs in the vicinity of the Contact fault.

Little Percy mine.—The Little Percy mine is situated a short distance south of the Ruby, and shows very nearly the same conditions. The chief workings consist of an incline which starts on the hillside at the outcropping of the Contact fault on the east limb of the Aspen Mountain syncline. This incline runs in a northwesterly direction for over 1,300 feet, having a varying pitch. For most of this distance it is in the Leadville dolomite, or in the Contact fault, which is marked by a brecciated zone containing large fragments of shale and porphyry. From this incline there run out at intervals

ten horizontal drifts. Of these the upper ones find ore, and there is also some in the lowest or tenth level. The chief ore is associated with much barite and is thoroughly oxidized. It contains a great deal of a bright-red powder, probably oxide of lead, often inclosed in barite crystals. There is also, in blotches, a rich dark-brown stain, which is thought by local chemists to be an oxide of copper, and which is taken by miners as an indication of richness. There are a number of small east-west slips in the mine, along which ore appears to have made. There are also some slight faults marked by breccia and open watercourses, which have formed subsequent to the ore deposition.

Best Friend mine.—The Best Friend mine is situated a short distance directly south of the Little Percy, and has most of its workings on the Contact fault. The shaft runs down through porphyry, then through about 30 feet of shale to the Silver fault. In places in this mine the Silver fault comes down very close to the Contact fault, so that the two are separated only by a very thick limestone breccia. The Contact fault is marked throughout by a brecciation which is not very profound, and by a persistent seam of lime mud. This seam varies in thickness from an inch or two up to over 20 feet. It is beautifully stratified, sometimes cross bedded, and when thickest is composed of fine lime mud alternating with coarse sandy layers. In the thickest portions this mud has evidently filled large caves. The stratification grows finer toward the top of this deposit, and on the bottom is a seam, which seldom exceeds 4 or 5 inches in thickness, where the fine clay is stained very black by oxide of manganese. A sample of this gave on analysis 45.86 per cent of manganese oxide, with 12.83 per cent of iron oxide. It was also assayed and found to be impregnated with silver to a certain extent. Above the mud seam is almost invariably limestone, while below it is dolomite; and the ore is nearly continuous with it, generally lying in the dolomite beneath. The width of ore is comparatively slight, the thickest pay streak in the mine thus far being only about 20 inches. In character the ore is similar to that of most of the mines in Tourtelotte Park, being entirely oxidized and containing much barite; and from the oxides of the metals it derives a general brown color, locally red or yellow.

The following series of probable events in the history of the rocks in this mine may be inferred from the phenomena along the Contact fault:

First, the formation of a fault which is parallel to the bedding, or

nearly so. This is indicated by brecciation between the blue limestone and the dolomite. Second, the mineralization and deposition of vein material. This is shown by the fact that the breccia along this fault has been changed to ore, and has in large part been cemented by vein material, chiefly barite. The mineralization, therefore, is later than the faulting. Third, dolomization. This was probably contemporaneous with the mineralization, but may have gone on somewhat later. It is indicated by the alteration of the blue limestone in the immediate vicinity of the Contact fault to dolomite. The irregular distribution of this dolomite, following fractured zones and occurring in nonpersistent bands and blotches, shows that it could not have been originally deposited, but that its deposition came about through the waters which circulated through the fault zone. Fourth, a movement of the rocks at a later period and a widening of the original fissure. This must have left an open fissure of varying width. The opening of this fissure subsequent to the ore deposition is shown by the fragments of ore as well as of limestone and dolomite in the clay which subsequently filled it. Fifth, the deposition of bog manganese during a period when the waters which filled the opening were comparatively quiet. Sixth, a slight tilting of the rocks, which is shown by a gentle dip in the mud layers and by some disturbance in the manganiferous lower layer, which is often broken. Seventh, the deposition by a more rapid and muddy current of the sandy and limy layers.

At the southern end of the mine a fault is encountered which may be the Dixon. This cuts off the Contact fault and the ore, and although there is blue limestone on both sides, showing that the throw has not been great, the other side has not yet been sufficiently explored to show the exact amount of displacement.

Bob Ingersoll mine.—The Bob Ingersoll mine immediately adjoins the Best Friend to the east, the workings of the two mines running together. The general occurrence of the ore and its nature are exactly the same as in the Best Friend. From the Bob Ingersoll an incline runs down on the Contact fault to the north and encounters the Hallet fault, which runs into it at the end of the incline. This shaft is 210 feet deep, and has passed through porphyry and Weber shales to the Silver fault, at the contact of shales and blue limestone. This contact is brought down by the Hallet fault to about the level of the Contact fault at the end of the incline. At

the bottom of the shaft a rich bed of ore was found, which was, however, comparatively small, turning out $65,000.

Dixon shaft.—This shaft, which is about 270 feet deep, runs through porphyry and the Weber shales to the Silver fault. Below the Silver fault dolomite was reported, which probably resulted from secondary dolomization accompanying ore deposition. Drifts from the shaft cut the blue Leadville limestone in its normal place below the fault. The main drift runs slightly south of west and cuts the Dixon fault, which has a slight downthrow on the south side, as shown on the map and in the sections. There has been some mineralization in this mine along the Contact fault, but there seems not to have been any large amount of pay ore found.

Mayflower tunnel.—The Mayflower tunnel is situated on the west side of Tourtelotte Park, on the slope of the hill toward Castle Creek. It is one of the tunnels which cut the formation where it has an easterly dip, on the western limb of the Aspen Mountain syncline. It starts in dolomite and runs east about 240 feet to blue limestone, the contact between the two formations being very sharp. After about 100 feet of blue limestone there comes a heavy breccia of shale and altered limestone, with occasional porphyry fragments. This is probably the Silver fault. In this breccia there are some very good seams of ore, especially one at the contact of the breccia with the hard limestone below, which is here locally dolomized.

San Jacinto shaft.—This shaft cuts the western limb of the Aspen Mountain syncline, starting in porphyry and crossing the shale into the Silver fault, then passing through the blue limestone into the Contact fault, and thence for some distance into the dolomite. The only ore found in the workings was some lead ore on the Contact slip.

Sam Houston shaft.—The Sam Houston starts not far from the San Jacinto, and, like it, in porphyry. From the porphyry it passes through shale to blue limestone on the under side of the Silver fault. Some ore was found in the blue limestone, about 15 feet below this fault.

Saddle Rock shafts.—There are two shafts on the Saddle Rock property, one of which lies near the Sam Houston. This shaft shows essentially the same conditions as the Sam Houston, except that it passes through a larger body of porphyry. After the porphyry, it goes through shale and limestone into the dolomite. There seem to have been two ore-bearing

zones in this mine, one at the Silver fault, in which the ore lay mostly in the blue limestone, and one at the Contact fault, in which the ore was mostly in the dolomite.

The second Saddle Rock shaft is situated on Saddle Rock, between Keno and Ophir gulches. This shaft runs in altered limestone after passing through a slight thickness of Weber shales. Two levels from the shaft run east and cut the Sarah Jane fault only a short distance away, showing that the alteration of the limestone in the shaft is undoubtedly due to the proximity of this fault. According to these developments the fault is here vertical, or has a very steep dip to the east.

Camp Bird shaft.—The Camp Bird workings are situated on the outcropping eastern limb of the syncline, at a point where this fold has become very shallow. There is, therefore, no very great difference in the elevation of the workings, which are mostly on the Contact fault. The ore is mainly on the Contact fault, but follows certain definite zones, so as to make ore shoots lying in the fault. The most marked of these shoots runs northeast and southwest. It is cut off on the north side by the surface and on the south side by the Silver Bell fault, which separates this mine from the Iowa Chief. This shoot has a variable width, averaging perhaps not more than 100 feet. The ore is a softened and brecciated brown-stained limestone, having bowlders of typical blue limestone and also of frosty-lustered dolomite. Above this comes usually blue limestone and below it dolomite, the thickness of ore varying from a few inches to 30 or 40 feet. The shoot has, therefore, a northeast trend and a pitch of about 25 degrees to the north, with a restricted extent east and west and a comparatively slight thickness. Together with the inclosing formations it is displaced by an east-west fault which has a downthrust on the north side of about 50 feet. This fault is barren, but on following up the fault plane the continuation of the shoot is found on the south side. The movement, therefore, came about subsequent to the mineralization. From here the ore shoot is traced continuously southward to near the Silver Bell fault, where it is finally lost, being faulted away by the parallel slips which lie close to the Silver Bell.

Another large ore body forms a so-called "chimney." This is a nearly vertical shoot, which was followed up continuously from the Contact fault to the surface, ore being stoped out all the way. There seems to be no definite lateral trend to this chimney. At other localities in the

mine ore has made along the Contact fault at the intersection with vertical fractures, some of which have a north-south trend, while others run east and west. Pl. XLI, *B*, is a cross section in a northeast direction through the Camp Bird mine, and is extended into the Iowa Chief. It shows the ore as actually developed along the Contact fault, and its relation to the ore in the Iowa Chief.

Iowa Chief mine.—The working shaft of the Iowa Chief mine is called the South Camp Bird. This shaft passes through 165 feet of porphyry and then 15 feet of shale to the Silver fault. Below this fault it passes through 100 feet of blue Leadville limestone, often dolomized and stained brown, but it does not seem to have reached the Contact fault and the main body of Leadville dolomite. A considerable amount of ore has been taken from this mine, some of it of a very high grade. Although on about the same level as that of the adjacent Camp Bird mine, the ore is actually at an entirely different geological horizon, for while in the Camp Bird it occurs all along the Contact fault between the blue limestone and the dolomite of the Leadville formation, in the Iowa Chief mine it is found along the Silver fault, which separates the blue limestone from the overlying porphyry, with a small belt of broken shale between. The ore-bearing horizons of the Camp Bird and Iowa Chief mines are separated by the Silver Bell fault. This has a downthrow on the south side of 200 feet, so that it brings the Silver fault down very nearly to the same level as that of the Contact fault in the Camp Bird. The Contact fault in the Iowa Chief lies below all the workings, and has not been at all prospected, although it is extremely probable that ore exists along it, as it does in the Camp Bird.

The actual occurrence of the ore and the other geological features of the mine are shown in Pl. XLI, *B*, in which the Iowa Chief mine occupies that portion to the southwest of the Silver Bell fault, at the left-hand part of the plate, while the right-hand or northeastern half of the section belongs to the Camp Bird. This section has been carefully made, and shows only actually developed ores. As seen here, the ore occurs altogether in the vicinity of the Silver fault, either in the actual zone of displacement or in the dolomite immediately below it, where it has formed along minor slips in the limestone parallel to the main fault. This ore is a soft, decomposed, pulverulent limestone, containing much barite, with no copper or zinc and very little lead. There is little or no dolomite in the rocks inclosing the ore,

which are almost entirely pure blue limestone. In the ore bodies themselves, however, there often occur barren portions which are nearly pure dolomite. This shows that dolomization was attendant upon the ore deposition. The ore bodies are often separated from the inclosing barren rock by polished and striated surfaces, evidently belonging to fractures which were made at the same time as the main Silver fault. Along these fractures the limestone has often been triturated so as to form the so-called "talc" of the miners.

Celeste and Edison No. 1 mines.—The Celeste and Edison No. 1 shafts start in porphyry and run down through shale across the Silver fault into blue limestone, and from here down to the Contact fault and the dolomite. Ore is found at two main horizons—the Silver fault and the Contact fault. The ore in the Silver fault seems to have been rather richer than in the lower horizon, while the workings are rather more extensive on the Contact fault. The ore is identical with that in other mines of the park, being a limestone which has been replaced more or less by metallic minerals, with a gangue which is chiefly barite. This ore has been nearly all oxidized, so that it is soft and crumbling. Its value is very variable, ranging from a few ounces in silver to several hundred. There is in the lower workings, which run upon the Contact fault, a permanent floor of dolomite, which is brown from the oxidation of its iron. Above the ore at this horizon is generally blue limestone, which, however, is usually altered and may be dolomized. In the drifts may be seen irregular bands or tongues of dolomite, which follow the strongly fractured zones and cut straight upward across the blue limestone. There is, therefore, evidence of two periods of dolomization in this mine, one of which existed before the faulting, since it has been faulted regularly in the same manner as the blue limestone, and another which was subsequent to the fault, since it has been formed in the limestone along fractured zones which accompanied this faulting. It is significant that the miners call the dolomite where it occurs with the ore "vein lime," recognizing the fact that it is nearly always present in connection with the ore. Through the Edison there runs an east-west fault which has a slight downthrow on the north side of from 20 to 50 feet and which appears to be the same fault as that running through the Good Thunder mine. Along this fault ore has made continuously in the breccia, the stopes at one point being 60 feet high.

On the lower level of the Celeste a drift runs a short distance northeast

and cuts the Justice fault, crossing from brown dolomite to Weber shale. The dip of the fault here is about 65 or 70 degrees northwest, and it has a northeast trend. Along it the shales have been bent and broken.

Good Thunder mine.—There are two shafts on the Good Thunder claim, called the upper and the lower shafts. Both start in porphyry and go down across a thin belt of shale, through the Silver fault and the blue limestone, to the Contact fault. The ore occurs almost exactly as described in the Edison No. 1 and the Celeste, in shoots along the Contact fault, between the blue limestone and the dolomite, and is of the same nature, being all oxidized and containing much barite. There is also some ore in the dolomite in small slips which are apparently parallel to the main Contact fault.

Little Lottie mine.—The Little Lottie mine is situated close to the Good Thunder and Celeste, and a little farther south. The workings are not very extensive, but considerable ore has been taken out. The first horizon from which ore was taken was the Contact fault, between the blue limestone and the dolomite; but subsequently the Silver fault, between the shale and the blue limestone, was explored, and considerable ore was found. A short distance southwest of the Little Lottie shaft is a tunnel which runs in a southerly direction, starting in the Weber shales and crossing the Silver fault into the blue limestone. The Silver fault in this tunnel is marked by a breccia 10 or 15 feet thick, which is underlain by a soft gray sand consisting of separate grains of dolomite. The limestone along the fault has been somewhat mineralized, showing often considerable barite, and some ore has been stoped out both in the limestone and in the shale.

Justice mine.—There are two shafts on the Justice claim, the northern or lower shaft and the southern or upper one. The lower shaft starts on the east side of the Justice fault and goes down through porphyry till it cuts the fault, which here has an easterly dip. There are some bunches of ore found in the fault, but they appear to be earlier in age than the fault itself, and to have been dragged in by fault movement. The upper shaft is deeper than the lower, being about 400 feet deep. Accounts of the formations which this shaft passed through are conflicting, but after the evidence is sifted it appears probable that there was no porphyry in the shaft, but that it started directly in shale after passing through glacial drift. The bottom is in the Contact fault. From the shaft an incline runs off to the northwest along the fault, which dips about 40 degrees. At intervals along this incline

there is some ore, both in dolomite and in blue limestone, which shows a tendency to follow certain shoots along the Contact fault. The end of the incline is in a highly brecciated zone, which is probably near the Justice fault. Just southeast of the shaft there is a series of stopes which have a northeast-southwest trend and are nearly vertical. Along these ore has been taken out continuously from the Contact fault up through blue limestone to the overlying shale. This shoot continues northeast until cut off by the Silver Bell fault. The ore is a broken and mineralized blue limestone, and its walls are smooth and distinct. It is evident that it formed along a fractured zone in the limestone, although neither the dolomite below nor the shale above shows any displacement. This ore shoot, in the language of one of the miners, was "the bonanza of the park."

The ore is in general low grade, is entirely oxidized, and contains a large amount of barite, thus corresponding with most of the other Tourtelotte Park ores.

Last Dollar, Minnie Moore, and O. K. mines.—The Last Dollar, Minnie Moore, and O. K. form, with the Justice, a continuous series of workings underlying the upper part of the Tourtelotte Park basin. Most of these workings run on the Contact fault, and consist of inclines dipping with the fault about 30 degrees to the northwest, from which levels run out. The Contact fault in these mines is remarkable for the immense amount of low-grade ore which is formed along it. This ore is in many places practically continuous, and presents to the eye the appearance of great mineralization, since it is soft and pulverulent, is stained red and yellow with metallic oxides, and contains a large amount of barite. Most of it, however, has a very low amount of lead and silver, and the large amount of barite is a disadvantage, so that thousands of tons have been uncovered which can not be profitably shipped. Along this mineralized zone the rocks show the influence of dolomization and of silicification.

Those ore bodies which are of higher grade and which have been profitably shipped seem to occur in steeply dipping fractured zones which traverse the Contact fault. There are several such zones shown in the mine, some of which have an east-west trend, while others run north and south. Along these the ore has been followed up for varying distances, as is the case with the great ore shoot of the Justice (which has been called "the Canyon"), and these ore bodies have blue limestone on both sides.

In the O. K. such a mineralized zone has been followed up across the blue limestone quite to the shale, and there is rich ore lying immediately under the shale. The ore in these steeply dipping shoots is crushed and broken blue limestone, more or less dolomized, but with blue limestone on both sides a short distance away from the vein, and it contains less barite and more lead and silver than do the great masses of low-grade ore which are found everywhere along the Contact fault. The occurrence of the two varieties of ore under different conditions suggests two slightly differing periods of mineralization.

In the region occupied by these mines the porphyry sheet, which in the whole southern part of Tourtelotte Park and on Aspen Mountain lies very close to the Silver fault, seems to have cut up abruptly to the south across the shales, so that the amount of shales overlying the blue limestone is greatly increased and the porphyry disappears altogether. Thus the Last Dollar shaft, which is 465 feet deep, passed through 35 feet of glacial drift, about 220 feet of Weber shales, and then crossed the Silver fault into the blue limestone.

Little Rule tunnel.—The Little Rule tunnel starts just above the Contact fault, in a place where the original blue limestone has been entirely altered to dolomite. It runs east, following a bedded vein which contains a great deal of barite, but not enough lead and silver to make it profitable ore. The rock on both sides of this vein, above and below, is altered to dolomite, or "short lime," and is considerably iron-stained, especially near the vein. Near the end of the tunnel the rock, and with it the vein, becomes broken and shifted about. A little farther in the Sarah Jane fault is crossed, and the Weber shale, which lies on the east side of the fault at this point, is entered. There is not much mineralization along the Sarah Jane fault at this point, and very little pay ore has been found in the workings.

The Sarah Jane mine.—The Sarah Jane workings are mostly in a zone of shattered and highly altered rock in the vicinity of the Sarah Jane fault. Although much of this rock was originally blue limestone, it is now all dolomized. The ore, which is all oxidized, occurs in pipelike shoots, which run up through the altered rock. It is highly siliceous, as is also the rock in its immediate vicinity. Another peculiarity in the ore is the presence of a large amount of calcite.

Highland Light shaft.—The Highland Light shaft goes down through the Weber shale and crosses the Silver fault into the blue limestone. A small amount of ore has been taken out.

Hannibal mine.—The Hannibal shaft, which is directly east of the Little Rule tunnel, on the opposite side of the Sarah Jane fault, passed through approximately 200 feet of porphyry and a small amount of shale to the Silver fault below, where it encountered the blue limestone horizon, here almost entirely altered to brown "short" dolomite. At the bottom of the shaft ore occurs in what appears to be the Contact fault, or at the intersection of some more steeply dipping fractured zone with the fault. The ore zone is locally as much as 8 or 10 feet wide, and the pay streaks occur in shoots and chimneys in this zone. On the west side the ore has been cut off by a slight fault, which strikes north and south and dips 80 degrees to the east. This fault is probably auxiliary to the Sarah Jane.

Jay Gould mine.—The Jay Gould shaft passes through a small amount of shale into blue limestone which is irregularly dolomized and stained brown. At the bottom a drift runs northwest parallel to a slip in the rocks. This drift is partly in blue limestone and partly in dolomite, which probably results from alteration of the limestone. The workings show a considerable amount of the alteration which usually attends mineralization, such as the replacement of the lime in the rock by silica and the presence of crystallized calcite, but no pay ore has been found.

Buckhorn No. 2 mine.—The Buckhorn No. 2 has a shaft about 200 feet deep, which cuts the Contact fault about 75 feet from the collar. Ore is present in considerable amount in the Contact fault, on the west side of the shaft. This ore runs high in lead and baryta, and does not contain as much silica as does that of some adjoining mines. Where most of the ore has been removed a slight synclinal basin is exposed.

Long John shaft.—The Long John shaft is probably about 260 feet deep, and at this depth cuts the Silver fault. There is some ore in the Contact fault between the shale and the blue limestone.

Adelaide shaft.—The Adelaide shaft is 250 feet deep, and is mostly in altered, silicified, and dolomized rock which belongs to the Leadville formation. The workings are chiefly on the Contact fault, but no ore has been developed. It is a peculiarity of the rock in these mines, however, and in the neighboring mines, that while there has been no great minerali-

SPAR GULCH, FROM NEAR BEST FRIEND SHAFT.

zation, yet the process of silicification, which usually attends ore deposition, has gone on more extensively than in places where more ore has been found. This process results in the formation of zones of jasperoid, which follow fractured zones and faults, and by means of this jasperoid the faults may be traced continuously over the surface. Microscopic study of this rock shows that some iron was deposited at the same time with the silica, but apparently no great amount of the rarer metals.

TOURTELOTTE PARK MINING MAP.

The detailed map of Tourtelotte Park on the 300-foot scale comprises essentially the whole of the productive area, and in it are situated nearly all the mines which have been described. The region displayed is the same as that on the 800-foot map, but is slightly more detailed and comes out clearer by reason of the enlargement. On this map the blue Leadville dolomite and the blue limestone which overlies it are distinguished by different colors, and the Contact fault which separates it is represented as such, while on the 800-foot map both these formations are grouped together, and the Contact fault was omitted. There are also put in several small faults, which were not important enough to be shown on the 800-foot scale, but which are sufficiently well marked to be put into the more detailed map. Such a fault, for example, is that found in the Camp Bird mine, which is represented as a splinter of the Silver Bell fault running across to the Justice fault. The faults of the east-west system which have not been described in the 800-foot map of Tourtelotte Park have mostly been described in connection with the mine workings. There are seven cross sections and one longitudinal section, which show the geology as developed in the mines and on outcrops as accurately as possible. Nearly all the points shown have already been discussed, and a study of the map and sections will explain the structure far better than any written description could do. The ore bodies are not shown in the sections, but the occurrence of the ore in general throughout this whole area may be summarized as along the Silver and the Contact faults, or in the blue limestone which lies between these two.

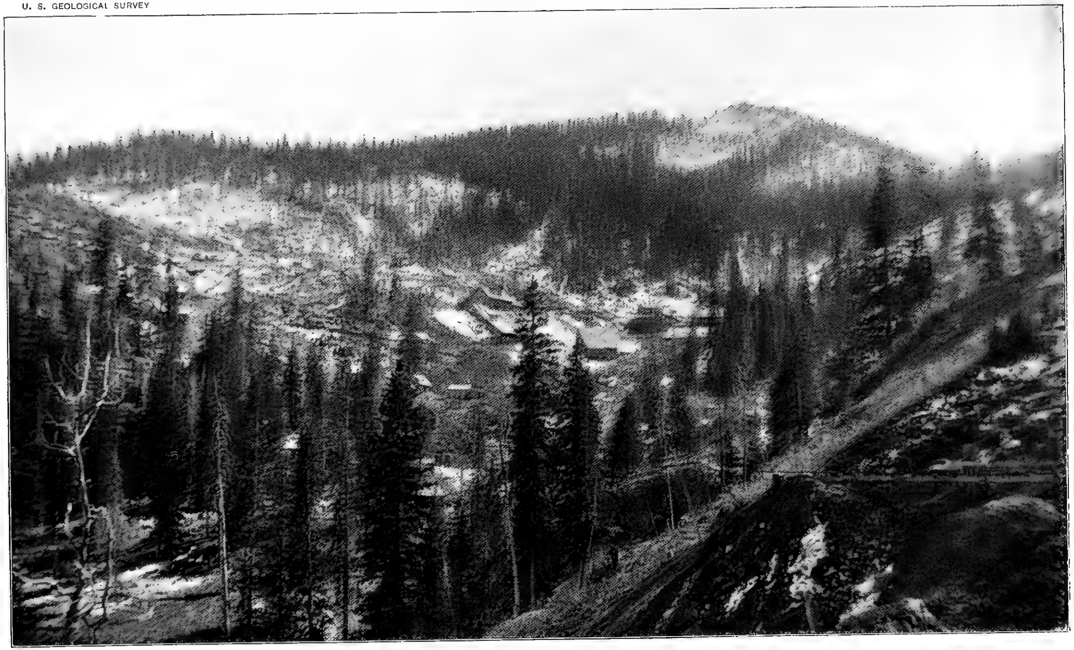
The accompanying plates give some idea of the general appearance of Tourtelotte Park. Pl. XXIII is a view taken from the west side of Spar Gulch, just north of the Best Friend shaft, and looks south up Spar

Gulch, with the head of Tourtelotte Park in the distance. The cliff in the foreground is of blue limestone, and is probably a sort of escarpment, determined primarily by the Hallet fault. At the left is Copper Hill, and on the hill at the right is the Dixon shaft house. Pl. XXIV is a view from a point farther south, overlooking the main Tourtelotte Park basin. This is taken from near the Camp Bird mine, and shows in the center the Last Dollar and Justice shaft houses. The hill in the background is outside of the Tourtelotte Park mining map to the south, and the Justice fault runs approximately through the depression in the center. Pl. XXV is a view, taken farther up the gulch, of an area shown in the upper left-hand corner of the preceding plate. It shows the uppermost workings of Tourtelotte Park near the point where the ore-bearing faults outcrop and pass into the air. At the bottom of the picture is the Last Dollar shaft house and dump, while farther up are the dumps of other mines, such as the O. K., Minnie Moore, North Star, and Silver Bell. At the left is Copper Hill, with the dump of the Copper King shaft on top. Beyond Tourtelotte Park the view looks across the Roaring Fork and other valleys to the summit of the Sawatch Range.

SMUGGLER MOUNTAIN.

Smuggler Mountain is outside the district of greatest disturbance, and does not contain any complicated faulting or folding. It has, however, been the source of enormous ore production, being intimately connected with Aspen Mountain and constituting the northern part of the rich mineral district which is centralized in Aspen Mountain and extends from the southern part of Tourtelotte Park to the valley of Hunter Creek. Workings are now nearly continuous between Aspen and Smuggler mountains beneath the Roaring Fork Valley. Although faulting in this region is not very extensive, yet there is developed in the mine workings, especially in the Smuggler and the Mollie Gibson, some complicated structure, which results from the action of faults of different systems and ages operating in a restricted field.

Pl. XXVI is a view of Smuggler Mountain, with the town of Aspen in the foreground. At the base of the mountain, just to the right of the center of the picture, are the shafts and dumps of the Mollie Gibson, Smuggler, and Free Silver workings, while the great dump of the Cowen-



TOURTELOTTE PARK, LOWER PORTION.

TOURTELOTTE PARK, UPPER PORTION.

hoven tunnel is a little farther to the left. In the gulch on the mountain side is the dump from the Johnson tunnel, which now forms part of the Della S. mine.

MOLLIE GIBSON MINE.

The so-called "contact" in the Mollie Gibson mine, along which most of the exploration for ore is made, is the Silver fault, which here separates the Leadville dolomite from the Weber shale. Between these formations there is a thick breccia containing fragments of blue limestone and occasionally of ore. An interbedded sheet of porphyry lies in the contact near the shale, sometimes separated from the dolomite by 20 or 30 feet of shale, sometimes resting directly against it. This is the situation from the Smuggler line on the north to a point 1,300 feet south of the Mollie Gibson shaft, where the edge of the blue limestone comes in between the shale and the dolomite. From this point the limestone wedge broadens very slightly toward the south, so that probably 40 or 50 feet is the maximum thickness in the Gibson workings. From the point of appearance of the blue limestone there are two "contacts," one between the brown dolomite and the blue limestone, and the other between the blue limestone and the shale. The former is the Contact fault, which is cut off by the Silver fault at the point where the blue limestone disappears to the north. The latter is the Silver fault, as before. Both these faults are marked by a crushed zone of rock, with polished walls. From the point of junction of the Contact and Silver faults southward the Contact fault is generally prospected for ore, although there is no reason why the Silver fault should not also be productive.

Gibson fault.—The Gibson fault, which belongs to the Della system, is displayed in every level of the Mollie Gibson. It has an east-west strike and a southerly dip of about 30 degrees, and faults both the Silver and the Contact faults. The lateral displacement or perpendicular separation of these earlier faults by the Gibson varies at different levels, showing that the latter fault diminishes with depth. In the fourth level the separation is about 105 feet, in the eighth about 70 feet, and in the tenth about 50 feet.

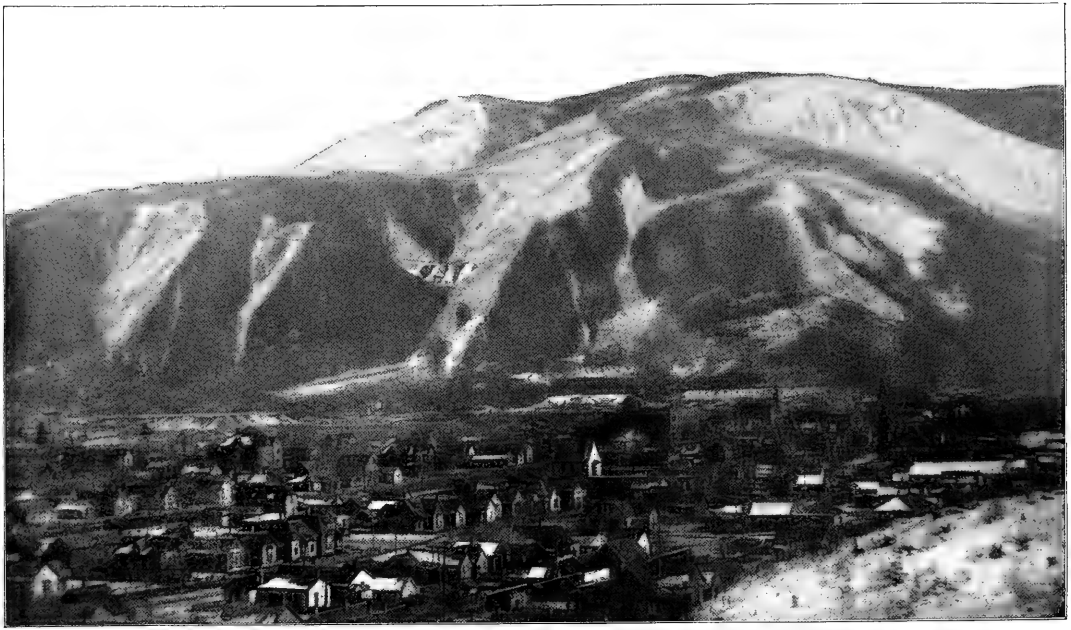
Emma fault.—On the seventh level, 220 feet north of the Gibson, is a fault having the same attitude and direction of movement. This movement, which is to the west on the north side, results in a perpendicular separation of about 35 feet. The fault is also shown in the ninth and

tenth levels, and is probably the same as that which cuts the 40-foot level of the Smuggler.

Smuggler fault.—The Smuggler fault comes into the Mollie Gibson mine on the ninth level north. At this point the perpendicular separation of the Silver fault by the Smuggler is about 70 feet, showing that the latter fault increases as it goes down.

Della fault.—The Della fault just cuts the end of the tenth level north in the Mollie Gibson mine, and is not otherwise displayed in the workings.

Clark fault.—There is evidence tending to show the existence of a fault nearly parallel with the Silver fault and only a short distance from it. This fault has displaced the original ore bodies which formed after the development of the east-west southerly dipping faults. This fault is recognized throughout the Mollie Gibson and Smuggler by the mine managers, and is called the Clark fault. On the fifth, sixth, and seventh levels of the Mollie Gibson it has been identified as a highly fractured zone, with dolomite on both sides, not far away from the Silver fault. Its general effect is an upthrow on the east side, so that the apparent dip of the ore-bearing rocks becomes much steeper. It is probable that this fault is not a single plane, but is rather a broad zone made up of many parallel faults, each of which has a downthrow on the west. In the upper workings of the Smuggler mine several of these parallel faults may be recognized, with the effect on the general dip which has been mentioned. On account of the approximate parallelism between the Clark and the Silver faults the former often lies between dolomite and shale, and in this case can not always be distinguished from the Silver fault. The best evidence which is offered as to the nature of this fault is the displacement of the peculiar ore bodies in the Smuggler and Mollie Gibson mines. The main Mollie Gibson ore body consists of a peculiarly rich ore, which contains a large amount of polybasite and native silver inclosed in flesh-colored barite, locally called pink spar. This ore occurs along the uppermost of the Della system of faults—the Gibson. Northward along the fault comes in lead and silver ore, not so high in grade, and finally ore very rich in zinc, such as is found only in a restricted region here and in a similar restricted region at Lenado. This zinc ore, consisting of mingled sulphides and carbonates, is found in the uppermost level of the Smuggler mine and crops at the surface in an open cut. In the Mollie Gibson the rich polybasite ore is cut off on the west side at the contact with



SMUGGLER MOUNTAIN.

the shales, and the nature of the contact between shale and ore shows the existence of a fault which originated since the ore deposition. From the point where the solid body of ore was cut off ore was followed along the fault plane for some distance, growing gradually smaller in amount as the distance from the main body increased, and finally becoming too poor to be profitably worked. This ore consisted of bowlders and angular fragments in the breccia and of native silver cementing the fragments, the last being evidently a secondary formation. In the Smuggler mine what appears to be the same ore body is found, having a general connection with the Smuggler fault, as the ore body in the Mollie Gibson has with the Gibson fault. In the Smuggler is found the same rich polybasite and native silver ore inclosed in pink spar. Above this, along the fault zone, comes low-grade

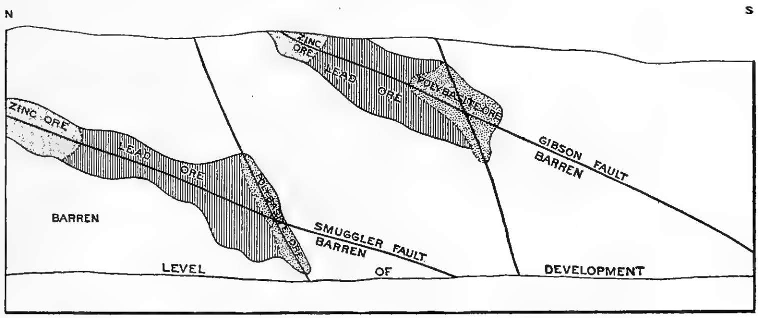


Fig. 7.—Diagram of Smuggler and Mollie Gibson ore bodies.

lead ore and a body of zinc ore, exactly identical in every respect with the zinc ore found at the top of the Smuggler shaft. Taking into consideration the fact that the ore body in the Mollie Gibson has been cut off by a north-south nearly vertical fault since the ore deposition, and that the Smuggler ore body is almost exactly the same as that in the Mollie Gibson, it seems probable that the two ore bodies were originally one and have been separated by this faulting. Since the east-west striking and southerly dipping faults were formed previous to the ore deposition, as is shown in both these mines, the displacement of the ore must have been accompanied by the displacement of the preexisting faults also. It follows from this that the Gibson fault along which ore occurs on the Mollie Gibson was originally the same as the Smuggler fault on which it is found in the Smuggler. Fig. 7 is an

idealized diagram showing the ore bodies in the Smuggler and in the Mollie Gibson, the section being taken along the plane of the Clark fault. Fig. 8 (see p. 199) gives a diagrammatic representation of the successive stages in the history of the rocks as worked out in the Mollie Gibson and Smuggler mines.

Occurrence of ore in the Mollie Gibson.—The main ore in the Mollie Gibson occurs on the Gibson fault, with dolomite below and shale above. Most of it was actually found in the shale, resting on a hard, polished, striated floor of dolomite. This ore was of a rich character, having large amounts of polybasite and native silver. In structure it was solid and massive, containing the polybasite in regular blotches or small true veins, and the large bodies showed banding conformable to the plane of the fault. These phenomena show unmistakably that the ore was originally deposited along the fault, and there is little evidence of movement since its deposition. The rich polybasite body appears to lie in a sort of subordinate shoot, trending south of east and lying on the Gibson fault plane. This shoot is marked by exceptionally large and rich bodies of a nature not found elsewhere in the mine. It is noteworthy that this rich shoot is practically the lower termination of the ore on the Gibson fault. Most of the ore below this is native silver, which, from the nature of its occurrence, is manifestly a secondary deposit leached from the rich ore above. Some of these secondary deposits are, however, of considerable size, and empty vugs are often found beautifully and elaborately festooned with delicate wires of silver. The Gibson fault becomes entirely barren a short distance farther down. Above the polybasite ore, however, the ore appears to be pretty continuous, but the amount of silver becomes less and there appears more lead and zinc. Farther up the zinc has formed in especially large quantities. At the intersection of the Gibson and the Clark faults ore has been stoped down for 100 or 200 feet. This ore was richest close to the main body and became progressively poorer with depth. It is a breccia which carries angular fragments of polybasite and pink spar, such as form the solid body above, and there is also a large amount of wire silver, evidently secondary, which has formed in the interstices of this breccia. The ore has been followed along the fault some distance north also, but is not found southward. This occurrence of ore in the breccia along the Clark fault shows that the movement was down and to the north on the west side; and this coincides with the

conclusion that the ore bodies of the Smuggler and of the Gibson were originally the same. At various points throughout the mine there are local formations of ore, which consist mostly of wire silver that has formed in the interstices of a breccia. These ore deposits, like some already described, are evidently of secondary origin, later than the main ore deposition.

Pl. XLI, *C*, is a geological section of the Mollie Gibson, made through the working shaft on an east-west plane. This illustrates the following features, which have already been described: First, the formation of the Silver fault, which separates the Weber shales from the Leadville dolomite; second, the development of the Della system of faults, which displaced the Silver fault with the surrounding formations and effected a general offset to the west on the lower or north side; third, the deposition of ore, which took place mostly at the intersection of the Silver fault with the later faults of the Della system; fourth, a movement nearly along the plane of the Silver fault, which, however, assumed locally a slightly different plane. This movement sometimes apparently coincides with the Silver fault, but ordinarily is more nearly vertical, and this has cut off the faults of the Della system and the ore which occurs along them. Thus the Gibson and the Emma faults are represented as cut off on the west side by this movement and as thrown down with the rock formations. The Smuggler fault at the extreme lower left-hand corner of the section was probably originally continuous with the Gibson, while the continuation of the Emma fault may well have been the Della, which is not represented in the section, but which lies below the Smuggler fault at about the same distance that the Emma lies below the Gibson.

SMUGGLER MINE.

In the Smuggler mine the zone which is usually followed for ore is, as in the case of the Mollie Gibson, the Silver fault, which separates the shale on the west from the dolomite on the east side. There is always a zone of fractured material along this fault, and generally parallel slips with polished and striated surfaces in the harder rock on each side. There is no blue limestone in place in the Smuggler, the east wall of the Silver fault being always dolomite. On the upper levels the dolomite is characteristic "brown lime," yellowish brown in color, and very closely jointed, or "short." In the upper levels, also, the shale is soft. In the deeper levels,

however, such as the eighth and ninth, which are as yet beyond the reach of oxidizing agents, the dolomite is hard and dark blue, with frosty luster, and the soft shales change to hard, black, argillaceous limestone. In several places there is exposed in the shale near the fault a sheet of porphyry, which does not appear to exceed 15 or 20 feet in thickness and which lies next to the dolomite.

Della fault.—The Della fault is well exposed in the Smuggler mine in the third, eighth, and ninth levels, having its usual movement to the west on the north or lower side.

Smuggler fault.—The Smuggler fault is shown in the Clark tunnel at the northern end of the mine. It is also shown in the tunnel level and in the eighth level, running parallel to the Della.

Emma fault.—The Emma fault, which is parallel with the Smuggler and the Della, outcrops at the northern end of the Smuggler "open cut" close to the shaft, and is seen in the 40-foot level, where its lower wall forms a smooth, polished, striated floor upon which the ore rests. This ore is that variety, rich in zinc, which is so characteristic of this shoot.

Clark fault.—Several of the parallel slips which belong to the Clark fault system are seen in the open cut of the Smuggler, and also in the Clark tunnel. They are nearly vertical in dip and have a north-south trend. They have a general upthrow to the east, causing a marked steepening of the line between the dolomite and the shale, which goes by the name of the "contact." Through the action of this fault the original ore bodies, as well as earlier fault systems, have been displaced.

Nature of ores.—Several varieties of ore are found in the Smuggler. The peculiar rich silver ore, made up of polybasite and native silver inclosed in flesh-colored or gray barite, which corresponds to the rich ore in the Mollie Gibson, is found in a continuous shoot in the seventh and eighth levels south. From this shoot of solid ore broken material was followed along the Clark fault, becoming progressively poorer as the distance from the main body increased, and finally, as in the case of the Mollie Gibson, becoming so low in grade as not to repay working. In the Smuggler, however, the train of crushed ore was followed upward from the main body, while in the Gibson it was followed downward. This circumstance, among others, goes to show that originally the two bodies were probably one. As in the Mollie Gibson, the rich polybasite ore is confined to this one

shoot. The majority of the other ores carry considerable barite and varying amounts of lead and silver. There is a great deal of low-grade ore consisting of altered dolomite carrying lead. In the upper levels this ore is oxidized and can not be profitably mined, but in the lower ones, where it occurs as a sulphide, it can be concentrated by mechanical processes and profitably handled when averaging only 8 ounces of silver to the ton.

Occurrence of ore.—The main occurrence of ore in the Smuggler mine is in connection with the Smuggler fault. Along this fault the ore has formed chiefly at two places, one at the south and one at the north end of the mine. The occurrence of the rich polybasite ore on the Smuggler fault on the seventh and eighth levels south has already been mentioned. At the northern end of the mine, at the Clark tunnel level, there are immense stopes out of which a large body of high-grade ore has been taken. These stopes are along the Silver fault at its intersection with the Smuggler fault above, and are continuous down from this level to the plane of the Della fault. The method of occurrence of the ore at this place is shown in Pl. XLII, *A*, while that of the rich polybasite ore at the southern end of the mine is seen in Pl. XLI, *D*, which runs through the Smuggler shaft. The Smuggler fault between these two points carries considerable ore at intervals, and at one point is marked by large bodies of oxidized zinc ore. This zinc ore, which is found in the third and fourth levels north, is identical with that found in the open cut near the shaft and on the 40-foot level at the shaft, and it is probable, as already stated, that these two bodies were originally one, and that they have been separated by the Clark fault.

SUMMARY OF MOLLIE GIBSON AND SMUGGLER GEOLOGY.

These two mines are distinguished from the rest of the camp in the possession of peculiar ore shoots, which are characterized by flesh-colored barite, by poverty in lead, and by a large amount of polybasite and native silver. Both of these ore shoots lie along east-west faults of the Della system, and have evidently formed along fracture zones which were developed subsequent to the Della faulting, but previous to the ore deposition. The existence of these fracture zones is shown by the nature of the ore, which is mostly barite containing angular fragments of the country rock, and thus has the character of a true vein filling. The lower-grade

ore, on the other hand, which lies on the Gibson and on the Smuggler faults side by side with the polybasite ore, is evidently a replacement or impregnation of the dolomite, and does not contain a large amount of barite or other gangue material. It seems probable that after the deposition of the low-grade ore, but before the cessation of the period of ore formation, these east-west fracture zones were formed, and that along these zones fresh solutions deposited the polybasite and barite. The native silver appears to be a product of alteration from the polybasite.

Evidence goes to show that subsequent to all the mineralization a fault was developed nearly parallel with the Silver fault, but slightly steeper. The effect of this fault was to throw the rocks on the west side downward and to the north. Thus the original polybasite ore shoot was divided into what are now the Mollie Gibson and the Smuggler ore bodies. This fault must have also faulted the preexisting faults of the Della system. On this supposition the Gibson fault and the Smuggler fault were originally one. Measurements show that the Gibson fault narrows going down, its perpendicular separation being about 50 feet in the tenth level of the Mollie Gibson and 110 feet in the third. The Smuggler fault, on the other hand, has a more important movement with increasing depth, so that 10 or 15 feet of perpendicular separation in the fourth level of the Della S. becomes 70 feet in the ninth level of the Mollie Gibson. There is abundant evidence of this postmineral faulting below the rich stopes of the Mollie Gibson, in breccias containing angular fragments of the ore, often cemented by native silver. Mine sections on Pls. XLI and XLII show the structure of the Smuggler mine as described. They are taken at opposite ends of the mine, one through the shaft and one through the great stopes at the end of the Clark tunnel.

COWENHOVEN TUNNEL.

The Cowenhoven tunnel starts on the north side of the Roaring Fork Valley at the base of Smuggler Mountain and runs under the mountain to a point below Hunter Creek Valley. It connects all the mine workings along the ore-bearing zone which lie north of the Smuggler mine, and is used for transportation and drainage. The tunnel starts in an almost easterly direction, and after passing through a considerable thickness of glacial drift runs into red and white arenaceous limestones and the gray

limestone which forms the base of the Maroon. Near the contact of the gray Maroon limestone with the Weber shales there is a heavy breccia, 40 or 50 feet thick, which shows movement, probably along a bedding fault. Near this fault zone the shales are bent from their normal position. After passing through a considerable thickness of shale some porphyry is traversed, and then shales to the contact with the brown Leadville dolomite, where the Silver fault comes in. There is no blue limestone in the tunnel, or indeed anywhere in the Smuggler Mountain mines. After cutting through the Leadville dolomite a little distance the Della fault is encountered, as a consequence of which the Parting Quartzite crosses the tunnel. Passing through the fault, the tunnel swings to the north until it again reaches the Silver fault, and from this point runs in a general northeasterly direction, in Leadville dolomite, not far from the Silver fault. Sometimes, however, it gradually diverges a considerable distance from the fault, as is the case opposite the Park Regent station, where the Parting Quartzite outcrops in the tunnel. The strike of this quartzite is nearly parallel with the trend of the tunnel, but is a little more easterly, so that it enters the tunnel from the south and passes out of it when the tunnel begins to curve to the north, as it does at this point. The curve in the tunnel was necessitated by the action of a small east-west fault, which is called the Regent. This has shoved the formations to the west on the north side. From this point the tunnel runs entirely in dolomite until in the Alta Argent mine another east-west fault is encountered, which has likewise a movement to the west on the north side. Just before reaching this fault the tunnel had again run so deeply into the Leadville dolomite that it is nearly down to the Parting Quartzite, so that on crossing the fault it runs into Silurian dolomite, the Parting Quartzite having been shoved over to the west side, where it probably soon runs into the Silver fault.

The Smuggler Mountain mines which this tunnel connects form a continuous series of workings reaching from the Smuggler on the south to the Alta Argent on the north.

DELLA S. MINE.

The Silver fault has been followed throughout the Della S. as the horizon on which ore most usually occurs. On the west side of this fault is the Weber shale, and on the east the Leadville dolomite, with no

intervening blue limestone. There are occasional blocks of porphyry in the breccia along this fault throughout the workings, and in the southern part of the mine a continuous band comes in at or near the fault. There are also bowlders of blue limestone in the breccia in the southern part of the workings, showing that the drag has been from the south.

Faults.—The Della S. fault has an east-west trend, and dips to the south about 30 degrees. It has an offset to the west on the north or lower side of about 200 feet. According to Mr. D. W. Brunton, striation on the fault plane shows that there has also been a southerly movement, so that the top block has moved southeast over the bottom. This is the only large fault in the Della S. mine, but there are many small ones, which are generally parallel to it and belong to the same system. None of them, however, appear to have over 50 feet displacement.

Occurrence of ore.—The ore occurs in the neighborhood of the Silver fault in certain localities. Throughout the mine there are recognized two streaks or veins—the foot-wall streak and the hanging-wall streak. The former is in dolomite on both sides, and is generally 5 or 10 feet from the contact with the shale. In some of the larger stopes below the tunnel, where the ore occurs in solid dolomite, the exact locality of the Silver fault is not known. The hanging-wall streak is in the Silver fault itself, or even in the shale above. At one place in the fourth level ore has been taken out 40 feet from the fault plane in the solid shale.

In the bottom of the Della S. incline were observed two bands of barite, which are conformable to the Silver fault. Each of these bands was about a foot thick and constituted rich ore. Between them was 5 or 6 feet of dolomite, which was mineralized so as to be profitably mined. The Silver fault was not seen here, for upon the highest barite vein there still lay barren dolomite. These veins, which constitute the so-called foot-wall streaks, as well as those forming the hanging-wall streaks, are evidently formed on slips auxiliary to the main Silver fault, on both sides of which they lie. In the dolomite these slips are especially well marked and seem to be indefinite in number. They are nonpersistent and are generally more or less mineralized. The slip nearest the main fault is nearly always the richest, being generally richer than the ore on the fault plane itself.

It is not at all points, however, that the Silver fault with its auxiliary slips in the dolomite and the shale has been made the locus of very

extensive ore deposition. Where the ore has been taken out in large quantities, as is the case in the Della mine, there are developed certain definite zones or shoots along the Silver fault which have been remarkably productive, while most of the other rock along this fault contains so little mineral as to be practically worthless. The most important of these ore shoots lies directly below the Della S. fault, where this comes into contact with the Silver fault. At the junction of these two on the lower side there are continuous stopes reaching from the Regent ground at the top of the hill down to the fourteenth level in the Della. These stopes are often immense, being in places 100 feet high, and they nearly always run quite up to the Della fault and there stop. The Della fault itself, however, is very slightly mineralized, as a general rule not being worth prospecting; but low-grade ore is frequently found along it, and in places bodies which are workable. The intersection of the Della fault with the Silver fault immediately above is practically barren, being mineralized to no greater extent than the Della fault itself. Another important shoot follows the Smuggler fault up through the Della workings. This fault grows slighter as it goes up, and is not always identifiable; but along it the ore shoot is large and continuous, and is entirely similar to that formed along the Della fault. The line of stopes is continuous to the bottom of the glacial drift. There are other well-marked shoots in the mine which have been followed out, and each of them seems to be connected with some slight fault or well-marked fracture zone, the ore occurring at the intersection of these faults or fractures with the main Silver fault.

Nature of the ore.—The ore in the Della S. seems to be of two distinct varieties. One of these is a dolomite which has been altered and softened, and which contains a paying amount of metals; but there is no large amount of vein material, and the process of mineralization seems to have been in large measure a replacement. The dolomite is yellowish brown in color, and is blotched with barite and sometimes with lead. The more common variety of rich ore is very high in baryta and poor in lead. It generally occurs in veins, made up chiefly of coarsely crystallized barite, and called "spar streaks." In this barite there occurs a small and variable quantity of gray sulphide, which is probably in part, at least, tetrahedrite or tennantite. This sulphide goes by the name of "gray copper," and occurs in blotches or in small vein fillings which are not persistent. A very

common and characteristic form of ore contains numerous small veins of tetrahedrite, which often form crosses in the barite. This peculiar ore goes by the name of "crisscross spar." The crosses are doubtless deposited at the intersection of microscopic cracks, and their occurrence shows that the metallic sulphide was later in deposition than the barite. This sulphide is highly argentiferous, and is always a valuable ore. On oxidation a small amount of green copper carbonate is formed from it, which stains the rock and is taken by miners throughout the camp as an evidence of rich ore. In places, however, this carbonate has been carried some distance and deposited in barren barite. This barren spar has then the appearance of ore, while it is actually destitute of value.

From the phenomena in this mine the following deductions as to the manner of ore depositions may be made: First, the formation of the Della fault preceded the ore deposition, since this fault has been one of the most important factors in determining the locus of the ore. Second, since it is on the under side of the Della and other faults that ore has formed, and since on the upper side the rock is nearly barren, it is probable that the ore-bearing solutions were ascending, and that they came up along the Silver fault to the Della, at which point they deposited their metallic contents. Third, although the barite is the gangue of the metallic sulphide, it was deposited in large measure before the richer metals were, since in the crisscross spar and similar ores the valuable sulphides have been deposited in cracks which were formed in the barite subsequent to its crystallization. These cracks are purely mechanical, such as might arise from any strain in the rock.

Although the Della fault existed previous to the ore deposition, yet there has been motion along it subsequent to this period. Indeed, there is evidence from the deformation of old raises and drifts that movement is going on along the fault at the present day. In most of the other faults there is also evidence of some movement subsequent to the ore deposition. This is true even of the Silver fault, where broken, angular fragments of ore may be found in the breccia.

Pl. XLII, *B*, is a section through the Della mine, showing the actual occurrence of the ore. Although the shape of ore bodies is somewhat generalized, the main ones occur as represented, in connection with the Della and Smuggler faults, while the Silver fault has also been very important in determining the locus of ore deposition.

BUSHWHACKER MINE.

The Bushwhacker mine lies next north of the Della S., along the Cowenhoven tunnel. The nature of the Silver fault is the same in this mine as in the Della, since it has solid dolomite on the east side, with shale on the west. Between the shale and the dolomite is a brecciated zone which is very thick, so that the solid shale has hardly been cut in the whole workings below the shaft. This breccia contains shale and porphyry, with large bowlders and slabs of blue limestone, but most of it is so ground up and altered that its original nature is not discernible. A dike of porphyry cuts across the northern end of the mine, as seen in the lower levels. From here it passes up through the Park-Regent, appearing on nearly every level. It has a width of from 2 to 20 feet and a dip of 60 degrees or less to the northeast, thus cutting up through the Leadville dolomite to the Silver fault. There are no developments to show whether it is continuous through the breccia of the Silver fault into the shale beyond, but, so far as has been seen, it appears to be faulted with the inclosing rock, for, on approaching the fault, it becomes squeezed and slickensided, and angular fragments of it are found embedded in decomposed limestone.

There are two main ore shoots in the Bushwhacker, as pointed out by the manager, Mr. Bulkley. These shoots are parallel. One reaches from the first to the third level, and is continuous north and south to the Park-Regent on one side and to the Della on the other; the second is along the sixth and seventh levels, and the two come together and disappear in the Park-Regent workings. Along these zones the stopes go up vertically for 40 or 50 feet, both the dolomite below the Silver fault and the ground-up material of the breccia being mineralized. Mr. Bulkley pointed out that both shoots are marked by slight faults which cause an offset to the west on the lower side, so that a kind of bench is made along the Silver fault; and it is along this bench that ore has been formed. The ore of these two shoots, however, was not exactly alike, the lower one being almost entirely a high-grade, heavy spar ore, containing much gray copper, while the upper one contained very little barite and carried much lead and some zinc. Besides the two most important ore channels there are several shorter ones, one or two of which have a northwest trend,

nearly at right angles with the main shoots. Except along these zones the Silver fault is practically barren.

Pl. XLII, *C*, is a cross section through the Bushwhacker mine and through the southern part of the Park-Regent mine, which lies at this point above the Bushwhacker on the Silver fault. The features which have been described in the Bushwhacker mine will be seen in this section, while those which belong to the Park-Regent will be next described.

PARK-REGENT MINE.

The nature of the Silver fault in the Park-Regent is identical with that which has been described in the Bushwhacker and Della. Most of the workings run in dolomite below the fault, although the solid shale which forms the hanging wall is cut in many places. Between the solid shale and the dolomite there are generally about 40 or 50 feet of broken blue limestone and shale; but sometimes the dolomite and the solid shale come very close together, with practically no intervening breccia. The dip of the fault diminishes markedly upward, and increases with depth. This is shown by the Iowa incline, which, at the point near the bottom of the Iowa shaft, is in solid shale, but soon runs into dolomite going down. Where the incline runs into the Cowenhoven tunnel there are exposed some of the shaly and dolomitic beds of the Parting Quartzite, which strike with the tunnel and dip steeply west. At this point, however, the tunnel turns so as to run upward across the formations, reaching the solid shale again in a short distance.

There is no continuous sheet of porphyry running parallel to the Silver fault in the Park-Regent, although there are occasional bowlders of it in the fault breccia. The dike which was noted in the Bushwhacker continues steadily across the Regent, and is last seen on the first or uppermost level.

Regent fault.—The Regent fault is marked in the tunnel by an offset to the west on the north side, the offset appearing to be about 30 feet. The main line of faulting is marked by a continuous open watercourse, traceable from the top to the bottom of the mine. From this main break south there is a series of parallel fractures, which are also often watercourses. The Regent fault appears to be nearly vertical in dip, and therefore to belong to a slightly different system from that of the Della fault.

Iowa fault.—Just east of the bottom of the Iowa shaft a vertical fault is well exposed, which thrusts up the Silver fault on the east side from 40 to 60 feet. This fault is probably a continuation of the Clark fault, which is shown in the Smuggler and the Mollie Gibson, or at least belongs to the same system.

Other faults.—At various places in the workings of this mine there is noticed a series of abrupt rolls in the Silver fault, which cause local flattenings, or benches, and these rolls may be developed in places into slight faults. The Della fault is exposed in the southern part of the upper workings, and the Parting Quartzite is seen running into the fault on the lower side.

Occurrence of ore.—The great Thompson stopes of the Park-Regent evidently lie near the intersection of the Della fault with the Silver fault above, and from the Della fault plane the ore was taken out up to the glacial drift. These stopes are now caved in so as to be inaccessible.

The ore now being taken out in the lower workings also lies in a decided shoot, which is marked by a continuous stope, extending at the time of examination from the tenth to the seventeenth level, a distance of about 400 feet. The long axis of this shoot is northwest and southeast, corresponding to the trend of the small faults belonging to the Regent system. Its width, taken in a northeast-southwest direction, appears to be about 150 or 200 feet, and the ore averages 5 or 6 feet in thickness. The general plane of this shoot is parallel to the Silver fault, but most of the ore lies in the dolomite, often with several feet of solid barren dolomite between it and the fault breccia. It is therefore formed along a slip parallel to the Silver fault. Throughout Smuggler Mountain these slips, which are often 50 or 60 feet away from the main fault, are frequently highly mineralized. The slip which lies close to the Silver fault in the dolomite is generally most productive, and is often more highly mineralized than the fault plane itself.

The two chief ore shoots of the Buskwhacker are continuous into the Park-Regent, converging toward the north, so that they probably meet near the Iowa incline. Where these shoots come together they are connected by no fewer than four distinct parallel northeast-southwest shoots, which carry a large amount of very rich ore. Along most of these shoots there are fractures or watercourses. The two slight faults which give rise to the main Bushwhacker ore shoots come together and end in a bench in the Park-Regent.

The section Pl. XLII, *C*, which passes through the Bushwhacker, also passes through the Park-Regent higher up. Near the upper part of the section the ore which was found in the Thompson stopes is seen resting on the Della fault and running up until cut off by the glacial drift. The occurrence of the other chief ore bodies in the mine is also shown, slightly generalized. Pl. XLIII, *A*, is a section of the northern end of the mine, taken through the Iowa shaft and the Iowa incline. The ore along this plane of section occurs, as usual, at the intersection of slight faults with the Silver fault. The upper shoot shown is that which lies at the point where the two main Bushwhacker shoots come together. The lower shoots are developed at the intersection of the Regent system of slight faults with the Silver fault, and show the ore as occurring in the dolomite and along the Silver fault at these intersections. The fractures of the Regent system are cut obliquely by the plane of this section.

MINERAL FARM MINE.

The Mineral Farm mine shows essentially the same peculiarities as its neighbors. Ore occurs in the immediate vicinity of the Silver fault, sometimes in the dolomite and sometimes in the breccia above. It follows certain nearly continuous north-south shoots, which probably mark some slight displacement or fracture. The ore is very high in baryta, the average being nearly 50 per cent. There is very little lead. Much of the barite is entirely barren of values, and from its nature seems to be a filling of preexisting fissures or cavities. These veins are often 2 or 3 to 10 or 12 feet thick.

ALTA ARGENT MINE.

The Alta Argent mine was the northernmost working mine along the Cowenhoven tunnel at the time of examination. The tunnel runs from the Mineral Farm into the Alta Argent in Leadville dolomite, with the Silver fault close by on the west side. It soon encounters a fault which runs directly across the tunnel, and is probably nearly vertical, having an offset to the west on the north side of 20 or 30 feet. A short distance farther on another fault is encountered, having a similar displacement, and between these are vertical open fractures and watercourses, which increase in number toward the north. The maximum amount of fracturing is encountered still farther north, where in a space 30 or 40 feet wide the watercourses are

closely set together, so that the tunnel had to be lagged in order to stand. Just before reaching this highly fractured zone, the uppermost beds of the Parting Quartzite come into the tunnel. On the other side of this zone, however, no Parting Quartzite is found, but only hard blue dolomite. Since this fault has probably, like the others, an offset to the west on the north side, the dolomite is Silurian; and this is confirmed by a crosscut to the west on the north side of the fractured zone, which shows the Parting Quartzite, considerably altered, abutting against the shale on the other side of the Silver fault. The horizontal shift along this fractured zone, which is called the Alta fault, may be approximated at 100 feet. From this point north for some distance the Silver fault separates the Weber shale from the Silurian dolomite.

The ore in the Alta Argent appears to lie between two of the northwest-southeast faults which have been described as existing in the southern part of the mine, and is found both in the dolomite and in the shale. It contains considerable barite, and crisscross spar is frequent. There is also much native silver.

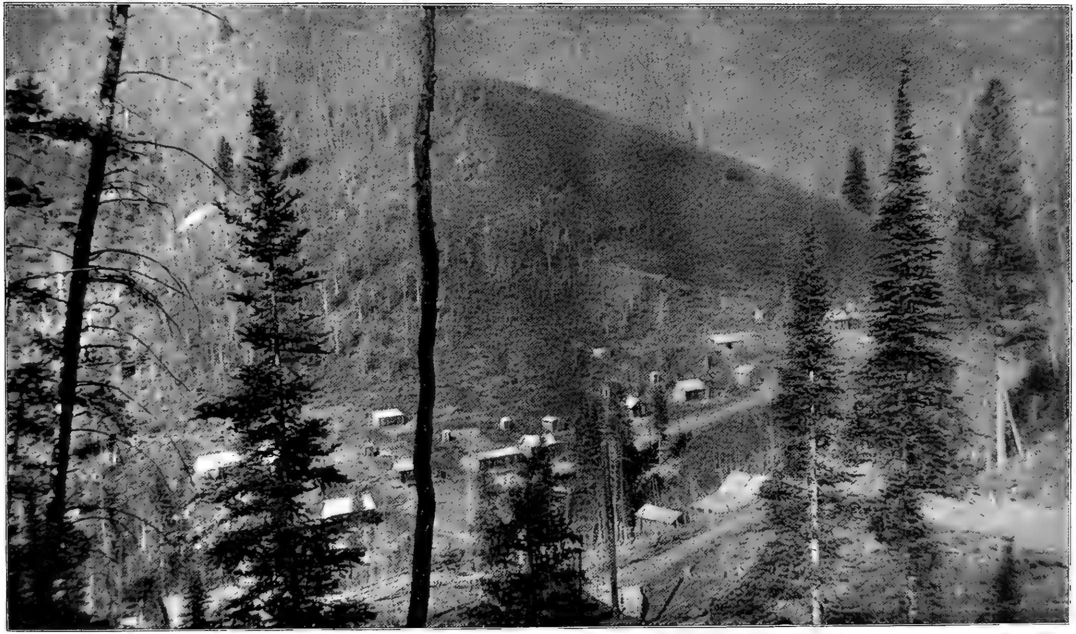
SMUGGLER MOUNTAIN MINING MAP.

The Smuggler Mountain map presents no areas of complication except along a narrow zone in the vicinity of the Silver fault. The Della and the Smuggler faults outcrop only in the northeastern corner of the district, but their dip is very slightly steeper than the slope of the hill, and they are found, therefore, in all the workings from the Regent to the Mollie Gibson. In the southern part of the district the Clark fault causes complications. According to the explanation which has already been presented, the Clark fault faults the Della S. system so that the Della and Smuggler faults are upthrust on the east side. Thus the Gibson fault, which belongs to the Della system, is brought close to the surface and locally outcrops, but as its dip is still slightly steeper than the slope of the hill this outcrop is extremely limited, being cut off both to the north and to the south by the Clark fault. The Gibson fault, on the other hand, cuts off the Silver fault, as do all the faults of this system. For some distance north of the Smuggler mine the Silver fault does not appear in outcrop, being cut off by the Clark fault. As the throw of the Clark fault diminishes, the line of junction with the Silver fault comes nearer the surface, until it crops, as shown

in Section C, Atlas Sheet XXVIII. From this point north the two faults crop very close together and parallel, and probably unite soon after leaving the area of the map. The displacement of the porphyry sheet in the center of the area is due to the action of the Silver fault and not to any subsequent movement. The geological features shown in the cross sections have been already described and do not require further mention. In studying the longitudinal section E, Atlas Sheet XXIX, however, it must be remembered that the various faults and other formation planes are cut by the section at varying angles, and so give varying lines of intersection, which are apt to mislead unless properly understood. In the center of the section the Clark fault is shown cutting the Della and Smuggler faults and upthrusting these faults, with the inclosing strata, to the southeast. It should also be noticed in this section how the Contact fault comes in at the extreme southern end, but soon runs into the Silver fault and disappears, leaving only a thin wedge of blue limestone between the dolomite and the shale.

RÉSUMÉ OF SMUGGLER MOUNTAIN GEOLOGY.

The structure of Smuggler Mountain is marked by uniform steep tilting, which has been disturbed at successive periods by faults. The first of these disturbing movements is represented by the Silver fault, which has cut out the blue limestone and part of the Leadville dolomite throughout the whole of the mountain, and also the thick sheet of quartz-porphyry which is intercalated in the Weber shales. Subsequent to the formation of this fault there arose a system of east-west breaks, of which the Della and the Alta faults are representatives. The Della fault has an east-west trend and a comparatively flat southerly dip, while the Alta fault, which also has an east-west trend, is nearly vertical. So far as can be judged from the phenomenon of ore deposition, however, these two faults were practically contemporaneous in origin. Subsequent to the formation of these faults there again took place a slipping along the general plane of the Silver fault, which locally deviated from this plane and so constituted an independent fault. This is called the Clark fault. The various stages in the deformation of the rocks on Smuggler Mountain are shown in the accompanying diagrams (fig. 8), A representing the original condition of the beds after the intrusion of the porphyry and the tilting away from the the granite axis, B representing the beds after the movement of the Silver fault, C showing



LENADO.

the effects of the Della fault, and D the structure resulting from the Clark fault, which is that existing at the present day. In determining the relative ages of these different fault systems the fact of the late ones cutting and faulting the earlier ones, as shown in the figures, is important. Valuable information is also obtained from the ore deposition, for the period of mineralization seems to have been restricted as compared with that of faulting. Thus the Silver fault was mainly premineral; the Della and the Alta faults began to form previous to the ore deposition, but continued after it, and the

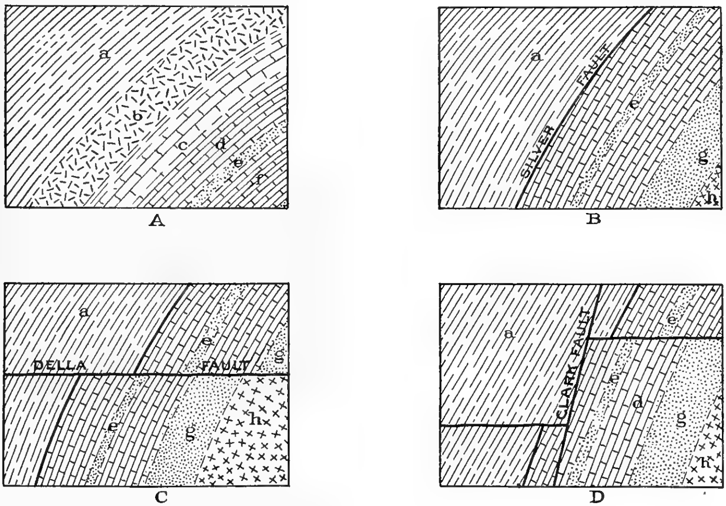


FIG. 8.—Successive stages of faulting in Smuggler and Mollie Gibson mines.

Clark fault is almost entirely postmineral, only secondary deposits of ore having formed along it.

LENADO.

Northward from the Alta Argent mine in Smuggler Mountain no ore has been found for several miles. Following along the metalliferous zone, the first productive locality is in Lenado Canyon, where the mining village of Lenado is situated. Pl. XXVII gives a general view of this village, now in a rather dilapidated condition. This view is taken,

looking across Lenado Canyon and up Silver Creek, from the hillside west of the creek, just above the Leadville mine.

ASPEN CONTACT MINE.

The Aspen Contact mine has its workings along the Lenado fault, which traverses the Lenado district from northeast to southwest. (See Pl. XXVIII.) The tunnel starts in Weber shales on the northwest side of the fault and runs southeast to meet it. On approaching the fault the shale becomes soft and decomposed, and the dip varies constantly from horizontal to vertical and pitches steeply in both directions, showing that the shale is crumpled into a series of complicated folds. From the shale the tunnel cuts into brown dolomite, which is probably Silurian. The contact of shale and dolomite is nearly vertical, and constitutes one of the parallel slips which make up the Lenado fault. The dolomite near the fault is much broken up, containing fragments of ore and of limestone. Near the fault workings run through the dolomite on a vein of rich blende, which was in places very high in silver and in lead. On the edges of the vein the sulphide has altered to zinc carbonate, with some lead carbonate. This vein was traced continuously for about 200 feet, trending with the shale-dolomite contact and only a short distance from it. In places its walls are smooth and straight, but they are slickensided, and are probably slip walls. In other places the vein is broken and interrupted by breccias and by faulted-in blocks of dolomite. It is probable that this ore was not formed in place, but existed prior to the faulting. A short distance southeast of the fault between the shale and the dolomite comes another fault, which separates the dolomite from the Cambrian quartzite. The two faults have the same general movement, but the displacement of the fault between the shale and the dolomite is greater. The zone between the dolomite and the quartzite, however, is greatly brecciated for many feet, and the quartzite is softened and decomposed. The ground-up rock is called "talc" by the miners, and is distinguished as "gray talc," "brown talc," or "blue talc," according as the quartzitic, dolomitic, or shaly material predominates. In this "talc" the richest ore in the mine has been found, lying directly under the quartzite, for here the fault dips steeply to the southeast, so that quartzite forms the hanging wall. The main ore body extended from the tunnel up to about 40 feet from the

ASPEN CONTACT MINE, LENADO.

surface, making about 200 feet. In places the ore was 40 feet thick, and laterally it ran along under the fault for as much as 300 feet. This ore contained much lead, a moderate amount of silver, and not much zinc.

The ore in the Aspen Contact mine, therefore, occurs in two chief zones, which are also fault zones; one at the contact of dolomite and shale, and one at the contact of dolomite and quartzite. Along both of these zones the ore is excessively broken up, and some of the very richest is in the finely ground fault material. Thus the ore does not seem to have formed in place, but to have existed previous to the fault; and as the faulting has been very extensive, the ore may have been carried a considerable distance. Pl. XLIII, *B*, is a cross section of the Aspen Contact mine, showing the occurrence of the ore and the various geological features which have been described.

The average ore is very high in zinc, generally containing much lead and a comparatively large amount of silver. Barite, on the other hand, which is such a common gangue mineral in other ores of the district, is very rare.

LEADVILLE MINE.

The geological features exposed in the Leadville mine are substantially the same as those in the Aspen Contact. The two branches of the main Lenado fault are cut in this mine, the first being between the shale and the dolomite, and the second between the dolomite and the quartzite. In the northwestern part of the mine, however, the steeply dipping Cambrian quartzite on the south side of the fault is overlain conformably by the Silurian beds, so that west of this point there is Silurian dolomite on both sides of this fault, and it becomes hard to trace.

In the Leadville mine there have been two chief ore bodies developed, both being, as in the Aspen Contact mine, in fault zones. One body was continuous with the main body of the Aspen Contact, lying between quartzite and dolomite in the more southern fault; and, as in the Aspen Contact, the ore was a lead and zinc sulphide, with some carbonate. The other main ore body lay in dolomite not far from its contact with the shale, and had a maximum width of 8 feet, from which it pinched in places down to a mere seam. In appearance this ore is like a soft mud, being blue-black, or more generally brownish blue, in color. As the so-called "talc" of the miners is often a triturated limestone, so this soft mud ore seems to

be derived from the trituration of sulphides. When richest it is nearly black, and is probably, in part at least, sulphide of silver with galena. The brown color is given by an admixture of yellow clay, which occurs in bunches and seams, and is of later origin. An assay of this yellow mud showed only 25 ounces of silver to the ton, while one of the blue-black material associated with it assayed 3,000 ounces. On both sides of the ore is brown altered limestone, which in places is brecciated and has fragments of soft black ore embedded in it. This ore, then, presents the characteristics of having been dragged into its present position.

BIMETALLIC TUNNEL.

The Bimetallic tunnel starts near the base of the Maroon sandstones and runs southeast across the Weber formation to the Lenado fault, which it crosses into the Leadville dolomite; farther on it goes through the Parting Quartzite into the Silurian dolomite. The information furnished by this tunnel is valuable chiefly as showing that there has at least been no general mineralization along the Lenado fault. The fault has been thoroughly explored in drifts from this tunnel and in raises and crosscuts, but was found to be absolutely barren, offering not even a trace of the precious metals in most places. It is well marked by a breccia of shale and dolomite.

TILLY SHAFT.

The Tilly shaft is situated in the gulch east of Silver Creek, which runs southwestward into Lenado Creek near the village. This shaft cuts the Silver fault, which here, as on Smuggler Mountain, separates the Weber shale from the Leadville dolomite. In this shaft some ore was encountered in hard blue dolomite. This contained considerable galena, but ran only about 5 or 6 ounces in silver. No ore was shipped from this mine, but the fact of its occurrence in this vicinity on the Silver fault is highly significant, especially as it seems to have formed in place. Pl. XXIX is a view of the gulch up which the Silver fault runs, with the dump of the Tilly shaft near the center.

RÉSUMÉ OF LENADO GEOLOGY.

In this district the beds have a generally westerly dip, which varies considerably in different localities. The chief displacement subsequent to the folding is that of the Lenado fault, which runs northeast and southwest,

GULCH ALONG SILVER FAULT, LENADO

is well determined by underground workings and by outcrops, and has a heavy downthrow on the northwest side. As is usually the case in faults, it does not necessarily consist of a single plane of movement, but of several, which include between them narrow slices of rock that distribute the total displacement. In the Aspen Contact and Leadville mines, for example, two of these interdependent faults are well exposed.

A large part of the fault is entirely barren of ore, the explorations in the Bimetallic tunnel being especially significant. In the Aspen Contact and Leadville mines, however, large quantities of rich ore have been taken out. Every characteristic of this ore shows that it was not formed in place, but was dragged into its present position by the faulting. The movement along the fault was nearly vertical, so that the rocks on the southeast side have probably dragged up this ore from some point almost directly below. Where this point is it is not possible to prove, but the fact that ore occurs in place along the Silver fault in the Tilly shaft is significant.

Section A of the 300-foot map (Atlas Sheet XXX) shows the probable depth of the Silver fault between the shales and the Leadville dolomite on the northwest side of the Lenado fault, in the region of the Aspen Contact mine, and it is very probable that the ore may have actually been dragged up along the Lenado fault from this lower horizon. The Silver fault, which is displaced by the Lenado fault, is shown only on the northeast corner of the map as it runs down into Woody Creek. Its continuation on the southeast side of the Lenado fault is not shown, since it runs into this fault a short distance beyond the southern edge of the mapped area.

Section A is taken through the Aspen Contact tunnel; Section B through the Bimetallic tunnel. The geology shown in both these sections has already been described.

QUEENS GULCH.

On the west side of the Castle Creek fault, and southwest of Tourtelotte Park, there is considerable mineralization in a strip beginning in Ophir Gulch and extending southward. In many places small quantities of rich ore have been discovered, and it is possible that in the future the district may become a heavy producer. One of the best opportunities for studying this mineralization is in Queens Gulch. Pl. XXX is a view of Queens Gulch taken from the west side of Castle Creek and looking across the

intervening valley. The Castle Creek fault crosses the gulch near the point where it appears to branch, not far from the center of the plate, and here is situated the Dubuque tunnel. The ore in this district is found along the Castle Creek and its dependent faults.

Dubuque tunnel.—The Dubuque tunnel (see Pl. XLIII, *C*) starts in the yellow and brown sandstones of the Maroon formation on the west side of the Castle Creek fault, and runs east through the gray siliceous limestone which forms the base of the Maroon. At some distance in, it enters Weber shales, much broken up, which soon change to a veritable breccia, in which shale and porphyry are commingled. On the east side of this comes solid porphyry, which is considerably softened and decomposed, and beyond this again is shale and porphyry-breccia nearly to the Castle Creek fault. On the west side of the fault the rock is hard black chert, evidently a silicified limestone. On passing through this granite is reached. The dip of the Maroon beds near the mouth of the tunnel is about 60 degrees to the northeast. The sequence of beds shown from west to east is the normal succession, consisting, after the sandstone and gray limestone at the base of the Maroon, of shale, then porphyry, then shale again, and finally the silicified limestone next the fault, which may be the blue Leadville limestone. The thicknesses of these formations, however, are much less than normal, and the nature of the contacts show that they are fault contacts, so that there is probably some displacement. These faults are nearly vertical, being mainly parallel with the Castle Creek fault, and so do not diverge much from the bedding, which is also very steep. On both sides of the porphyry, to the east and to the west, are especially well-marked zones of crushing. That to the east has been called the Dubuque fault, while that to the west, which is also found in the Little Annie mine, is called the Annie fault. There are, however, many smaller slips parallel to these.

The chief ore in the Dubuque tunnel is the zone of silicified limestone which lies next the granite. This silicified rock contains pockets of copper pyrite and galena, which do not appear to have great continuity. There is often a good deal of barite. At the contact of Weber and Maroon there is another mineralized zone which dips steeply to the east with the formations, but it does not appear to be very rich. There is a similar zone farther west, in the Maroon limestones.

QUEENS GULCH, FROM WEST SIDE OF CASTLE CREEK

Centennial tunnel.—The Centennial tunnel started in porphyry above the Dubuque and crossed eastward through the Castle Creek fault into the Cambrian quartzite. At the end of the tunnel a raise was made up to the Silurian dolomite.

Gray Carbonate tunnel.—On the hill above the Centennial and Dubuque tunnels the Gray Carbonate tunnel runs into Silurian dolomite, and there exposes a small amount of ore, some of which has been shipped.

Yopsie tunnel.—The Yopsie tunnel starts on the crest between Queens and Yopsie gulches. It runs in gray grits and in the pure gray limestone belonging to the base of the Maroon formation for a considerable distance, following a perfectly distinct vertical vein. This vein is of barite, often copper stained, and in the rock on both sides there are many parallel fractures. Both vein and fractures trend northwest, parallel to the Castle Creek fault. The heavy spar, however, is practically barren of valuable minerals, and thus affords another proof that the barite and the metallic sulphides were not necessarily deposited at the same time.

LITTLE ANNIE MINE.

The Little Annie mine is located on the Castle Creek fault, a short distance from the southern end of the area mapped. Its workings are in porphyry and shale on the west side of the fault, and it also crosses the fault into the Silurian dolomite. West of the main fault a series of just such dependent breaks as were noticed in the Dubuque tunnel exist and are shown in the cross section on Pl. XLIII, *D*. The fault between porphyry and shale has been called throughout the district the Annie. The shales on the west side of the porphyry are generally disturbed, especially close to the fault, being bent and squeezed between the minor slips, but farther away their attitude becomes more uniform.

In the lower levels of this mine the ore is a sulphide of lead, zinc, and silver, with a considerable amount of barite. The galena is sometimes beautifully crystallized, and the silver is often found native. The ore occurs chiefly in the immediate vicinity of the Castle Creek fault, but on the west side of it, being developed along many of the slight faults and fractures in the shale and porphyry. Some was also found in the dolomite on the east side, but these deposits were apparently not so extensive. In the upper levels the ore is oxidized.

CHAPTER IV.

CHEMICAL GEOLOGY.

In this chapter the various chemical changes which have occurred in the rocks of the Aspen district since their consolidation will be discussed. Nearly all of these changes have come about since the beginning of deformation in the beds, and they have apparently an intimate connection with the physical changes, such as faulting and folding, which have been described in Chapter II. From an economic point of view the most important of the chemical changes was that resulting in the deposition of the precious metals, but certain other changes are much more widespread, and thus are more important geologically. These latter changes consist in the alteration of limestone to dolomite by a process of replacement, and, by other processes of replacement, in the alteration of limestone and dolomite, but chiefly the former, to quartz and to iron. These processes of dolomization, silicification, and ferration are all intimately connected with the deposition of the precious metals, but are more widespread, as might be expected from the great amount of magnesia, silica, and iron throughout the crust of the earth as compared with the smaller amount of the rarer metals. All these chemical changes have occurred mainly at the same period and apparently through the same agents, but the process of ore deposition requires more peculiar and unusual conditions than do the others, and therefore probably acted during a shorter period than they.

DOLOMIZATION.

As seen under the microscope, all the dolomites of Aspen have essentially the same structure, and this structure is clearly not that of a sedimentary deposit. The dolomite crystals which make up the larger part of the rock are all apparently crystals of the double carbonate and occur mostly in nearly perfect interlocking rhombohedra, and associated with these are invariably small grains of quartz whose character and shape show that they

are chemical segregations and not detrital. This structure is sufficient evidence that the dolomite is not a simple sediment, such as most limestones are, but has crystallized through the influence of solutions. There are only two possible methods, broadly speaking, by which such solutions could have acted to bring about this result. First, the dolomite crystals may have been precipitated originally as such from sea water highly charged with salts of magnesium and calcium; and, second, the process may have been metasomatic, the solutions having acted subsequently to the deposition of the rock and thus produced the crystalline dolomite which now exists. The idea that dolomites are formed by direct chemical precipitation by sea water has been somewhat advocated,[1] but is not largely held at the present day. Bischof[2] has shown that when a solution containing carbonates of lime and of magnesia becomes so highly saturated that precipitation begins, the lime carbonate will nearly all precipitate before the deposition of magnesia carbonate begins, owing to the difference in solubility between the two salts, and that there would thus result a lower layer of nearly pure carbonate of lime and an upper layer of nearly pure carbonate of magnesia. From the mingling of the two layers some small amount of dolomite might be formed, but no thick and continuous bed could thus be precipitated. In addition to this theoretical evidence against the direct chemical precipitation of dolomite is the practical evidence that no such precipitation is now known to be going on.

The second possible way for the formation of dolomite, namely, by metasomatic interchange between the materials of an already deposited rock and other materials brought by permeating solutions, is the one which has seemed most probable to recent writers. This secondary origin is in many cases actually proved, and the rock from which dolomite is formed by alteration is always limestone. Dana[3] has described the interesting case of the elevated coral island of Metia, north of Tahiti. On analysis the white compact coral limestone of this island was found to be nearly a true dolomite. From the general character of this rock it appeared to have been deposited in the shallowing lagoon of the small coral island, and to have been derived from an abrasion of the coral. Deposits of mud are frequent

[1] T. Sterry Hunt, Chemical and Geological Essays, p. 92.

[2] Chemical and Physical Geology, English translation, London, 1859, Vol. III, p. 170.

[3] Manual of Geology, 4th edition, New York and London, 1895, p. 133.

under such circumstances. The ordinary reef-forming corals, however, contain very little magnesia, and therefore the formation of this dolomite seems to be connected with the peculiarities of the lagoon in which it is deposited. Such a landlocked lagoon is a very favorable place for the evaporation of water and the concentration of the salts which it contains, and these concentrated salts of magnesia are supposed to have acted upon the coral so as to form dolomite. In the same way dolomite may be formed over wide areas where a previously deposited limestone is covered by the shallow waters of a landlocked and evaporating sea.

On a more local scale the alteration of limestone to dolomite has been observed by various writers. Such alteration along joints in the Carboniferous and Devonian limestones near Cork, in Ireland, has been described by Professor Harkness.[1]

The nature of the exact chemical process in this alteration has not been definitely agreed upon, the chloride, the carbonate, and the sulphate being variously considered as the possible magnesian salt which has reacted upon the carbonate of lime. More recent investigations, however, seem to show that any or all of these salts may have this effect. The general chemical reason for the formation of dolomite seems to be the tendency of the carbonates of magnesia and lime to unite to form a double carbonate.

ASPEN DOLOMITES.

In Aspen there is evidence of two distinct periods at which dolomite was formed. The main body of dolomite, consisting of the whole of the Silurian beds and the lower part of the Leadville formation, existed previous to the deformation of the rocks by faulting and folding, since the dolomite beds are faulted in the same proportion as the rest of the strata. Along these main faults and fractures, however, the blue limestone at the top of the Leadville formation has been altered irregularly for varying distances on each side of the fractures into dolomite, microscopically identical with that formed at the earlier period. This later dolomite forms wherever the rock has been open to circulating waters. Thus it follows faults and fractures which cut directly across stratification, and also slip planes and porous zones conforming with the stratification. In the latter case the dolomite forms apparent beds in the blue limestone, as is especially well seen in the

[1] Quart. Jour. Geol. Soc. London, Vol. XV, 1859, p. 101.

neighborhood of the Contact fault as it outcrops on Aspen Mountain, where, in the blue limestone cliffs above the fault, dolomite has formed in zones parallel to the bedding along slips of the same nature as the Contact fault itself.

The origin of the dolomite belonging to the earlier period has been discussed in the first chapter. It is there shown that both the Silurian dolomite and that constituting the base of the Leadville formation are continuous over wide areas, with an almost uniform chemical composition. The structure of the rock, as observed, is indicative of the fact that the dolomization came about through the action of solutions, but the great extent of these beds shows that these solutions could not have been local or dependent upon any local cause. The agents which produced the alteration of the original calcareous sediments to dolomite must have operated equally over the whole area in which we now find these beds dolomized. Such widespread solutions would be afforded by the presence of a great lake or inland sea in which the usual amount of magnesia in sea water was concentrated by evaporation.

The origin of the dolomite belonging to the later period, however, was evidently distinct from that which has been suggested for the extensive beds. As before, the microscopic structure shows that the rock was produced by the action of solutions which exchanged carbonate of magnesia for part of the original carbonate of lime, but in this case the solutions have been comparatively scanty and short-lived, for they have not affected the whole rock, but only zones along watercourses. In the extensive beds of dolomite belonging to the earlier period the change is practically uniform and complete. This has been proved in the case of the Leadville dolomite by a number of analyses, such as are given in Chapter I, p. 25. These analyses show a comparative uniformity throughout the rock, and show that the whole formation is nearly a true dolomite, having a slight excess of lime. This dolomite, as also that which originated later, always contains some iron and silica, which were introduced probably at the same time as the magnesia. On the other hand, analyses of the locally dolomized zones which traverse the blue limestone show all transitions from a pure dolomite into a pure limestone, the dolomization growing less as the distance from the fracture along which the dolomizing solutions apparently flowed increases. To test this fact, analyses were made of rock

from a locality on the top of Aspen Mountain, on the divide between Keno Gulch and the broad depression on the north side of the mountain. Across this divide the Saddle Rock fault runs, having blue limestone on the east side and granite on the west. Four samples were selected from this vicinity for analysis, being taken out of tunnels which cross the fault and penetrate the blue limestone below. Nos. 1 and 2 are of samples taken along the main fault zone. Nos. 3 and 4 are from different points about 100 feet east of the fault, where the limestone was only partially altered.

Analyses of rock from dolomized zones of Aspen Mountain.

No.	SiO_2.	CaO.	MgO.	Fe_2O_3.	FeO.
1	1.02	33.74	16.76	2.10	.06
2	13.63	35.98	8.25	1.88	.64
3	31.12	37.28	.54	.36	.19
4	7.78	38.85	9.97	.88	.22

Study of these analyses shows that they represent four distinct transitional stages in the passage of limestone to dolomite, and that the dolomization is also accompanied by a corresponding ferration, while the amount of silica varies. Thus No. 3 is nearly pure siliceous limestone, while No. 1 is not far from the composition of the average dolomite.

This local dolomization almost invariably accompanies the ore. Even when the latter is in blue limestone there is usually a sort of envelope of dolomite around it, which in turn is surrounded by the limestone. In rare cases, when the ore is directly inclosed in blue limestone without such an envelope, its analysis shows the presence of magnesia, while the limestone is almost entirely pure.

The microscope affords means to trace the alteration of the blue foraminiferal limestone into dolomite in its various stages. In this process the coarse calcite becomes broken up into smaller crystals, which assume the rhombohedral form and the yellowish tinge distinctive of dolomite. The characteristic structure of the blue limestone persists for a time during this alteration, but becomes fainter as the crystallization proceeds. The coarsely crystalline calcite and the cryptocrystalline variety which form the two distinct phases of the blue limestone both become finely crystalline dolomite, but the texture of the two varieties continues different for some

time. The dolomite often incloses small grains of pyrite, or is stained by disseminated limonite.

A peculiar structural feature which evidences the secondary origin of the dolomite, both that in the extensive beds and that of the later period, is the prevalence of many closely set joints, which characterize the rock in its fresh condition. Furthermore, most of the dolomite belonging to the later period seems to have formed in the vicinity of watercourses, and since its formation it has been peculiarly liable to oxidation from surface waters, which have flowed continually along these courses, even up to the present time. The result of this has been the alteration of a certain amount of carbonate in the rock, with possibly the removal of some carbonate in solution. This has brought about a marked reduction in bulk, so that this dolomite is always very close jointed, or, as called by the miners, "short." A part of the carbonate in the fresh dolomite is iron carbonate, and on oxidation the yellow limonite resulting from this stains the rock, thus giving rise to the name "brown lime," by which, also, the dolomite is known at Aspen.

AGENTS OF DOLOMIZATION.

From the distribution of the dolomite belonging to the later epoch along the fault zones and other channels where water has for a long time circulated freely, it is evident that waters have been the agents of change. It may now be well to inquire what was the nature of this circulating water. Harkness, who has been quoted as describing similar dolomization along joints in limestone near Cork, in Ireland, attributes the change to sea water which penetrated downward along these channels. Bischof[1] mentions dolomite as accompanying ore deposits in limestone in France, and Adolph Schmidt[2] also finds that in the large lead and zinc deposits of Missouri the limestone has been dolomized along fissures and in the neighborhood of the ores. Both these latter writers refer the change to the action of solutions of magnesium bicarbonate.

Leaving out of the question the chemical changes which the waters that circulated along these faults and fractures have wrought in the rock, their more ordinary effects are strikingly like those of the water which still circulates through these channels at the present day. From the Castle

[1] Chemical and Physical Geology, English translation, London, 1859, p. 179.
[2] Trans. St. Louis Academy, 1875.

Creek fault in Queens Gulch a copious spring, which indeed is really the outbreak of an underground stream, rises between the Weber shales on the one side and the quartzite and dolomite on the other. In the Aspen mine the water which circulates along the Aspen and other faults comes down into the main Durant tunnel in a veritable waterfall, the roar of which can be heard a long distance away. These waters, which evidently come mainly from the surface, do not appear to exercise any dolomizing influence on the limestone which they traverse, and the phenomena of dolomization, silicification, and ore deposition along the faults show that the waters which produced them were in some way more potent than the cold waters which now circulate underground.

DOLOMIZATION AT GLENWOOD SPRINGS.

In this connection the waters at Glenwood Springs, which is 40 miles from Aspen, at the junction of the Roaring Fork and the Grand River, are highly interesting. The formations at the junction of the Roaring Fork and the Grand are the same as those exposed at Aspen. A short distance above the town of Glenwood Springs is the Archean granite, over which comes Cambrian quartzite, and then dolomite. The section was not carefully measured, so that an accurate description of the deformation which it has evidently experienced can not be given. The Parting Quartzite, however, was not found, and it is probably obscured by faulting. At the main springs, close to the town, the rock is pure blue limestone, like that at Aspen, and undoubtedly belongs to the same formation. The faulting which has been referred to is evidenced by many parallel vertical fissures, which are well exposed on the canyon walls. These become prominent a short distance down the river from the point where the granite outcrops, and are progressively more pronounced farther down. In the blue limestone on the walls of the canyon are great, vertical, irregular, open chambers, whose rounded walls show that they have been watercourses. In the immediate vicinity of the principal spring the disturbance has developed into a sheeting so prominent as to obscure the stratification. Along the fractures, for half a mile above the main spring, small springs of hot water, giving off sulphurous fumes, gush out at intervals. The one noted farthest up the river is in Cambrian quartzite. The open watercourses in the higher rocks have evidently been occupied by springs similar to these at a

very recent period. The existing springs follow by preference the vertical fractures, along which they appear originally to rise, but also follow porous zones in the bedding. At the main spring, which is called the Yampa, the water apparently rises in the strongly fractured zone which has been mentioned. According to the prospectus of the Colorado Hotel, which is built near this spring, the Yampa spring has a flow of 2,000 gallons per minute, and has a temperature of 120° F. The following analysis of the waters of this spring by Dr. Charles F. Chandler, of New York, is taken from this prospectus:

Analysis of water from Yampa Spring, Glenwood Springs, Colorado.

[In one United States gallon (231 inches).]

	Grains.
Chloride of sodium	1,089.8307
Chloride of magnesium	13.0994
Bromide of sodium	0.5635
Iodide of sodium	Trace.
Fluoride of calcium	Trace.
Sulphate of potassium	24.0434
Sulphate of lime	92.3861
Bicarbonate of lithia	0.2209
Bicarbonate of magnesia	13.5532
Bicarbonate of lime	24.3727
Bicarbonate of iron	Trace.
Bicarbonate of soda	Trace.
Phosphate of soda	Trace.
Alumina	Trace.
Silica	1.9712
Organic matter	Trace.
Total	1,250.0411

Besides the salts mentioned in the analysis, the water gives off various gases, among which sulphureted hydrogen and carbon dioxide are particularly noticeable. At the time of examination an artificial cave was being constructed along one of the small feeders to the main spring for the purpose of furnishing Turkish baths. When visited, the temperature in this cave with entrance open was 110°. With the entrance closed it is said to be 130° or 132°. In the bottom of this artificial cave hot sulphur water

bubbles up through fractures in the limestone. Most of these fractures are yellow, and apparently somewhat altered, while the rock a short distance away is perfectly blue and fresh. Four samples were selected for analysis, and the results are given below. No. 1 is the analysis of a specimen taken several feet from any fissure, which apparently had not been affected by circulating water. Nos. 2 and 3 were from the walls of different fissures along which water had flowed previous to the opening of the cave. No. 4 consisted of broken fragments lying in the bottom of a cavity formed by the rising hot water.

Analyses of rock from a cave near the Yampa Spring, Glenwood Springs, Colorado.

No.	SiO_2.	CaO.	MgO.	Fe_2O_3.	FeO.
1	.06	55.81	Trace.	None.	None.
2	.23	55.49	.24	0.9	
3	.22	55.17	.21	Trace.	
4	21.45	40.64	.73	.97	.23

These analyses show a progressive change from the first, through the second and third, to the fourth, consisting in an abstraction of part of the carbonate of lime and its replacement by silica, carbonate of magnesia, and iron. This change is, then, a partial silicification, dolomization, and ferration now actually going on in the limestone at Glenwood Springs under the influence of ascending hot waters.

A number of other analyses were made from samples selected from this locality, which all lead to the same conclusion. In the Cloud Cave, which is a cavern in limestone some distance away from the springs, one sample was taken of the blue limestone forming its walls, and another of the limestone at the surface, a short distance away from the cave, but on the same horizon. No. 1 is the analysis of the sample from the cave, and No. 2 of the specimen taken from the outside.

Analyses of limestone from and near the Cloud Cave, Glenwood Springs, Colorado.

No.	SiO_2.	CaO.	MgO.	Fe_2O_3.	FeO.
1	.22	55.45	.24	.10	.10
2	.11	55.68	Trace.	.03	.07

The change shown by these analyses is an increase in silica, magnesia, and iron in the limestone which forms the walls of the cave, and the inference is that this change has been brought about by the waters which have formed the cave. A number of analyses were made in other places, especially along fractures in the blue limestone on the walls of the canyon, where hot springs had evidently recently circulated. These all led to the same result as above, and only two more analyses will be cited. Of these, the first was taken from a watercourse in the blue limestone where the rock was close jointed and had the appearance of the Leadville dolomite at Aspen, while the second was taken 10 feet away from the first, in hard and unaltered rock.

Analyses of close-jointed and of hard and unaltered rock from near Glenwood Springs, Colorado.

No.	SiO_2.	CaO.	MgO.	Fe_2O_3.	FeO.
1	1.96	32.14	18.72	.03	.35
2	2.27	53.79	.46	.14	

The change in this case is very striking, since the first specimen is nearly a true dolomite, while the second is nearly a pure limestone.

On inspecting the analysis of the water of these hot springs it is seen how capable they are of producing the effects of dolomization, silicification, and to a less extent of ferration. A noteworthy feature is the presence of a large amount of magnesia, which is supposed by Dr. Chandler to occur as chloride and as carbonate in nearly equal amounts. It is interesting to note, also, that the lime is precipitated mostly in the condition of sulphate, although there is also a great deal of carbonate. Both the chloride and the carbonate of magnesium are capable of replacing carbonate of lime to form dolomite, as has been shown by different chemists, and it is very likely that both act together here.

The phenomena along faults and fractures at Aspen are exactly the same as those along similar channels at Glenwood Springs, and the inference is that both were accomplished by the same agents. In Corundum Gulch, 14 miles from Aspen up Castle Creek, and thus in a nearly opposite direction from Glenwood Springs, there are said to be hot sulphur springs. In Aspen there are no hot springs, but in the Mollie Gibson mine there are

cold springs which carry a large amount of sulphureted hydrogen and which are apparently ascending. We may conclude, then, that the later period of dolomization at Aspen was probably due to the effects of hot springs rising along faults and fractures. These altered the limestone to dolomite by means of the carbonate and chloride of magnesia which they they held in solution.

SILICIFICATION.

Among the chemical changes which have taken place in the Aspen rocks since their formation the deposition of silica has been one of the most noteworthy. The processes of silicification may be divided into three. First, the conversion of sandstones to quartzite by filling of the interstitial spaces; second, the deposition of silica at the same time with carbonate of magnesia from oceanic or lake waters; third, the deposition of silica along fault and fracture zones and other watercourses subsequent to the disturbance in the rocks produced by faulting.

As an example of the process first named, the Cambrian quartzite is prominent. This has been formed from original sandstone by growth of the detrital grains of which the sandstone was formed, after the manner of crystals, the silica to supply this development being furnished by waters which penetrated the porous rock. In the Parting Quartzite series the same process has gone on, although not always completely. In the Dakota sandstone there are certain interesting phenomena attending the early stages in the change of the sandstone to quartzite. This formation is mostly sandstone, but contains thin intermittent bands of true quartzite. Often the quartzite is not even banded, but is in irregular nodules distributed along certain zones. The extension and consolidation of these bands and nodules would make the whole formation a quartzite similar to the Cambrian.

The second process of silicification is illustrated in the dolomite of the Silurian and the Lower Carboniferous. These dolomites are always somewhat siliceous, and the microscopic examination reveals the presence of quartz, which is generally evenly disseminated in small grains of varying size. On casual examination these grains appear detrital, but when carefully observed, instead of being rounded or even regularly angular, they are seen to be irregular and sinuous, presenting reentrant angles and sudden bays, such as could not possibly appear in grains which had suffered any

STRATIFICATION AND JOINT PLANES IN DOLOMITE, WEST ASPEN MOUNTAIN.

friction. The appearance, moreover, is not like that of detrital quartz, the grains being perfectly clear and free from any break or crack. These grains seem to have formed at the same time as the dolomite in which they are embedded, for one is often entirely inclosed in a single dolomite crystal. The intimate and invariable association of quartz and dolomite indicates that the two had a common and contemporaneous origin, and that the quartz grains resulted, like the dolomite which incloses them, from the replacement of an original calcareous sediment by silica, this silica being introduced into the calcareous beds by the same solution which brought the magnesia and produced dolomization. The theory which has been advanced in the case of the dolomization is that such solutions were the waters of a great shallow evaporating sea.

The third process of silicification has had by far the most widespread effects. This silicification has come about subsequent to the formation of faults and fracture zones in the rocks, and is localized along these and other watercourses. It is therefore distinctly later than the process which has formed the quartz grains in the extensive dolomite beds, by the same proof which shows two distinct periods of dolomization, namely, that the siliceous dolomite of the first period has been traversed and faulted by the fractures along which the dolomite and silica have subsequently been deposited, replacing the limestone which lies above the Leadville dolomite. In the earlier-formed Silurian and Carboniferous dolomites the effects of this later silicification are seen, although not nearly so prominent as in the Leadville limestone. In these dolomites there have formed, along fractures developed at the main period of disturbance, bands and nodules of chert. Such bands and nodules often follow the stratification, having been formed along channels parallel to the bedding. In some places there are two sets of chert bands developed, one following the stratification and another cutting across it. Such is the case in certain parts of West Aspen Mountain. Pl. XXXI is a view of a cliff of dolomite near the point of the mountain. The stratification planes of the dolomite dip steeply down toward the right-hand corner of the picture, while there is a strong vertical jointing running nearly at right angles to the bedding. In places this jointing becomes so prominent as to obscure the stratification. In this rock the chert nodules sometimes follow by preference the bedding planes and sometimes the joint planes. Where the jointing obscures the bedding

and the chert seams follow the fractures the plane of jointing may easily be mistaken for that of stratification. Under the microscope the process of formation of this chert is seen to be an introduction of many tiny quartz grains along slight areas of shearing or fracturing, such areas being usually marked by microscopic zones of brecciation. When this process has gone on sufficiently far a chert band results. This chert is made up of cryptocrystalline or chalcedonic silica, and usually contains many small bodies of carbonate. Some of the larger bodies are irregular and evidently residual, while the smaller ones are mostly concentrated into rhombohedra, which commonly show a zonal structure, indicating growth by successive additions.

It is in the Leadville blue limestone, however, that the process of silicification along fracture zones is best shown. The various stages of change by which a rock consisting almost entirely of carbonate of lime is transformed into one made up chiefly of quartz have been carefully observed under the microscope. Often in a single section a change from typical foraminiferal limestone to quartz is illustrated in all stages, one part of the section containing only quartz, while another shows no change from its original condition. Usually, however, the process takes place gradually, and its beginning is signalized by the appearance in the limestone of many small, irregular quartz grains. Scattered here and there is also encountered a long and slender crystal of quartz which lies entirely surrounded by the fresh limestone, like a porphyritic crystal in an igneous rock. As the process of silicification progresses these slender crystals multiply, so that they finally join and form a peculiar and characteristic netlike or retiform structure. This network of imperfect quartz prisms incloses areas of calcite which are sprinkled with small, irregular quartz grains, varying in size down to the very smallest dimensions. Many of these small grains may be cross sections of prisms; they have not, however, hexagonal outlines, and their forms are irregular and often angular, recalling the universally distributed tiny quartz grains in the bedded dolomites. The final result of this silicification is the formation of a rock made up almost entirely of crystalline quartz grains of various sizes and shapes, in which the retiform structure is still predominant. There are also occasional small areas of crystalline calcite, which are probably residual. Accompanying the silicification is almost invariably a

small amount of ferration, the result of which is seen in the appearance of occasional hexagonal crystals of specular iron and, almost invariably, disseminated limonite. Often limonite occurs in numerous small rhombohedra, which are probably pseudomorphous after siderite, the siderite having probably formed from alteration of the original calcite.

The first stage of silicification is, as before noted, the appearance of isolated crystals of quartz in the limestone. A similar phenomenon has been noticed in most of the other metasomatic changes, such as ferration and ore deposition in general. The initiation of these processes is signalized by the occurrence of isolated, perfect crystals in unaltered rock, and these crystals enlarge or multiply until they join, and thus accomplish a complete replacement.

The rock that results from the complete silicification of limestone or dolomite sometimes resembles in the hand specimen a chert, but more often a fine-grained and altered quartzite. It is generally somewhat porous, its porosity arising from the leaching out of residual calcite areas, and it is usually drusy, with coatings of crystalline and chalcedonic quartz. Its color is usually red or yellow from the iron which it contains. This rock is one which is often found developed on a large scale in many mining districts, and has been studied by the writer at Leadville, where it occurs extensively in connection with the ore deposits. Its structure, appearance, and general method of origin are practically identical with the famous jasper of the Lake Superior iron regions.

During a study of the iron-bearing rocks of the Mesabi range in Minnesota[1] the writer pointed out that the word "jasper" was not a strictly correct name for this peculiar quartz rock, but concluded to retain it for the iron-bearing series. Since that time, however, he has become impressed with the widespread occurrence of this variety of quartz, which arises from the replacement of some original rock, ordinarily limestone or dolomite, by silica from circulating waters; and there seems to be need of some term which may specifically indicate it. For this use the word "jasperoid"[2] is suggested. Jasperoid may then be defined as a rock consisting essentially of cryptocrystalline, chalcedonic, or phenocrystalline silica, which has formed by the replacement of some other material, ordinarily calcite or

[1] The Mesabi iron-bearing rocks: Bull. Minnesota Geol. Survey No. 10, p. 135.

[2] Meaning a jasperlike rock.

dolomite. This jasperoid may be white or various shades of red, gray, brown, or black, the colors resulting from different forms of iron in varying proportions. This term covers in part what is known among the Western miners as flint, chert, quartz, etc., and also includes the so-called "jasper" of the Lake Superior regions.

So great has been the silicification along certain fault zones that these faults may be traced continuously by the blocks of jasperoid which outcrop or lie on the surface, for the jasperoid forms a dikelike body in the limestone. These zones are especially well developed in the southern part of Tourtelotte Park. Pl. XXXII shows in the center such an outcrop of jasperoid which has been left above the surrounding surface by differential erosion.

Silicification is always an accompaniment of ore deposition, both occurring under the same conditions. The former process, however, is more widespread, and hence has occurred not only in places favorable to ore deposition but along zones where there has been no mineralization of importance. Quartz formed by the replacement of the limestone is always present in the ores as a gangue. Some ores are especially high in silica, that of the Dubuque in Queens Gulch on the Castle Creek fault containing 40 or 50 per cent. This quartz occurs in the ore itself and extends from it out into the surrounding limestone, showing its great abundance and the easy conditions under which it is deposited. The phenomena accompanying the development of quartz in ore bodies are similar to those along fractures where there is no great mineralization. Where, as is often the case, it occurs in company with other gangue minerals, among the most prominent of which are barite and dolomite, the relation of all these shows that they have crystallized at about the same time and under the same conditions. All have evidently replaced the limestone, in which they generally form idiomorphic crystals which are often quite isolated.

From the association of jasperoid with dolomite belonging to the second period, as well as from the evidence which microscopic study affords, it is clear that the quartz was deposited at the same time and under the same conditions as the magnesia. In the case of the dolomite the conclusion has been arrived at that the change from limestone has been brought about by ascending magnesia-bearing waters, and it has been shown that such a change is now going on at Glenwood Springs. The

JASPEROID OUTCROP.

comparative analyses which were cited to prove this phenomenon at Glenwood Springs also show an accompanying silicification, which is actually being brought about by the ascending hot waters.

The effect of silicification along fault planes is seen not only in dolomite and limestone, but to less extent in other rocks. In the calcareous Maroon sandstone at the Yopsie tunnel, in Queens Gulch, the chief alteration accompanying the formation of barite and other gangue materials appeared, under the microscope, to be the accession of silica. This silica sometimes penetrates the rock along porous zones, where the original fragments are cemented by secondary silica, as in quartzite; or, in the more altered portion, the rock is recrystallized so as to resemble jasperoid. In granite lying against the Castle Creek fault in Queens Gulch the original quartz grains have been enlarged by secondary silica so as to present hexagonal idiomorphic outlines. These enlarged crystals have zonal structure, showing their method of growth.

FERRATION.

Another widespread chemical change in the rocks is the deposition of iron. This is frequent in limestone, where the alteration into iron has taken place along water channels, thus showing the secondary nature of the mineral. Almost invariably the ferration is only partial, and often extremely slight, accompanying dolomization and silicification. Along zones where these processes occurred the iron seems to have been originally deposited chiefly as carbonate, which crystallized together with the dolomite. Often, however, the microscope shows small crystals of pyrite embedded in ferriferous dolomite, and their relation is such as to indicate that sulphide and carbonate of iron have crystallized at about the same time, for the sulphide is confined to those areas where the calcium carbonate has been replaced by magnesium and iron carbonate. On oxidation the iron carbonate changes to oxide, thus giving the brown color which all oxidized dolomite has in this district. This oxidation brings out the iron in the rock more plainly under the microscope than when it is in the form of carbonate; and all the stages of change can be seen in partially altered specimens. After oxidation the iron shows a tendency to segregate, and so form nodules, and in the process of formation the iron of these nodules

actually replaces the original minerals. Where, as in sandy dolomite, the original rock consisted of dolomite and quartz grains, the iron replaces the dolomite first, and thus cross sections of the nodules show quartz grains embedded in iron oxide. These grains, however, have corroded outlines, and bit by bit they entirely disappear, showing that the iron also replaces them, although more slowly. The replacement of quartz by iron oxide in the process of concentration is best shown in the Cambrian quartzite lying close to the Castle Creek fault in Queens Gulch. Here is formed what appears to the eye to be a nearly solid iron ore, inclosing occasional small, irregular, residual portions of fine-grained, gray quartzite, which become stained yellow and brown and so grade off into iron. The structure of the rock is porous, with many small irregular cavities, the walls of which are lined with botryoidal or stalactitic brown limonite. Under the microscope the section is about nine-tenths pure iron oxide, mainly opaque, noncrystalline, specular iron, having a nearly black color, with a tinge of red, and a metallic luster. This oxide incloses many small irregular areas of crystalline quartz. Sometimes such an area is a small fragment of the quartzite, consisting of a number of grains, and upon the borders of this fragment the hematite is encroaching. The iron replaces first the secondary quartz which cements the grains, and so tends to surround and isolate them; but the irregular outlines of these separated grains show that the iron has affected them also, and it is evident that in course of time they disappear completely. This is a very satisfactory case of actual replacement. On the other hand, there are certain areas which are made up entirely of iron oxide, with no residual quartz. Instead of hematite only, there are here both specular iron and crystalline limonite. The limonite is translucent, with a rich golden-brown color, and is made up of many small crystalline fibers or elongated plates. The specular iron and the limonite are arranged in beautiful concentric rings, like those of agate or Mexican onyx. These concentric deposits often leave an irregular cavity in the center, the outlines of whose walls correspond to the shape of the concentric zones. The covering next these walls is generally a comparatively thick one of limonite, which is botryoidal in the hand specimen, and under the microscope is seen to be made up of long, slender, radiating crystals with spherulitic arrangement. This is a clear case of a filling of preexisting cavities.

Wherever there has been any rearrangement of the materials in the rock by circulating waters, with or without deposition of precious metals, a varying amount of iron has almost invariably been deposited. The Maroon calcareous sandstone in the Yopsie tunnel, in Queens Gulch, which has been cited as showing silicification, shows also an accompanying ferration. The granite which lies next the Castle Creek fault below the quartzite in Queens Gulch shows, among the new minerals introduced by waters which have circulated along this fault zone, veins and idiomorphic crystals of a carbonate which turns brown on oxidation and is probably ferriferous dolomite. In localities where precious metals have been deposited iron is always present as a metallic gangue. Often this iron is in the form of sulphide, but ferriferous dolomite or ankerite is also very common. This latter mineral is generally in the form of idiomorphic crystals, and occurs closely associated with barite and other gangue minerals, and from this association it appears that they were all formed at one time.

It appears from these facts that carbonate of iron crystallized at the same time and under the same conditions as quartz and dolomite, as well as certain other rarer minerals. On the evidence afforded by small areas of ferriferous dolomite containing pyrite crystals surrounded by unaltered limestone free from sulphide, it appears that iron carbonate and iron sulphide were probably at times deposited simultaneously. The alteration observed in the blue limestone at Glenwood Springs, which resulted from the action of ascending hot springs, and which has been discussed in connection with the question of dolomization, was characterized also by deposition of iron. In the unaltered rock iron is practically absent, while, as the process of alteration goes on, the amount of iron becomes very noticeable. This iron is doubtless deposited as carbonate, but, on oxidation, changes to ferric oxide, and so stains the rock brown. The fractures along which hot waters have formerly circulated at Glenwood Springs, but which are now dry, are prominent on account of this bright-colored oxide. It is possible, also, that some of the iron may at this place be deposited as sulphide, but this could not be determined accurately by analysis, on account of the sulphur which exists in the rock as sulphate, and no microscopic study was made.

ORE DEPOSITION.

NATURE OF ORES.

Near the surface the ores of the Aspen district occur as oxides, sulphates, and carbonates, mixed with sulphides, from which they are evidently derived. With increase in distance from the surface the oxides, sulphates, and carbonates disappear and give place to pure sulphides, showing that the latter was probably the universal condition previous to the action of surface agencies. The most important and common of these sulphides is argentiferous galena. Blende is also very abundant, especially in certain localities, and other sulphides are of less frequent occurrence. Pyrite and chalcopyrite, with occasional bornite, are also found. The sulphide ore in Dubuque tunnel in Queens Gulch contains a considerable amount of these. In the Mary B. tunnel on West Aspen Mountain the ore contains large, perfect crystals of iron pyrite, which carries small amounts of arsenic, lead, copper, zinc, cadmium, cobalt, and nickel. Tetrahedrite and tennantite are also very common. These minerals are called "gray copper" by the miners, and always form valuable ore, since they contain a large proportion of silver sulphide. An analysis of tennantite from the Mollie Gibson mine, by S. L. Penfield, is as follows:[1]

Analysis of tennantite from Mollie Gibson mine.

	Per cent.
Sulphur	25.04
Arsenic	17.18
Antimony	.13
Copper	35.72
Silver	13.65
Zinc	6.90
Iron	.42
Lead	.86
Total	99.90

In the Mollie Gibson and Smuggler mines there is much polybasite, which generally occurs in flesh-colored barite. Two analyses of this poly-

[1] Am. Jour. Sci., July, 1892, 3d series, Vol. XLIV, p. 18.

basite from the Mollie Gibson, by S. H. Pearce and S. L. Penfield, gave the following results when corrected:

Analyses of polybasite from Mollie Gibson mine.

	Per cent.	Per cent.
Sulphur	17.73	18.13
Arsenic	6.29	7.01
Antimony	.18	.30
Silver	59.73	56.90
Copper	12.91	14.85
Zinc	3.16	2.81
Total	100.00	100.00

This polybasite ore in the Smuggler and Mollie Gibson is reduced along watercourses to native silver, so that the ore consists of pink or gray barite bound together by irregular wires and masses of silver. As this process is attended by some loss of bulk, the ore also becomes much jointed and loses cohesion. The process of change is not completely understood, but it seems probable that the organic material in the Weber shales which lie around and against this ore has been active in the reduction. The gradual change of polybasite to silver around the edges and along crevices can be seen under the microscope.

Near the surface these sulphides are altered, there being a gradual transition between pure sulphides in the deep mines and pure oxidized minerals in the highest mines, such as those in Tourtelotte Park. The principal ore in these upper zones consists of earthy carbonates and sulphates, chiefly of lead (cerusite and anglesite); among the oxides hematite and limonite are very common, and the red oxides of copper and lead (cuprite and minium) occur in blotches in the oxidized ores, usually indicating the presence of silver. The black oxide of copper, melaconite, has been observed in thin coatings.

GANGUE MINERALS.

The gangues which accompany these sulphides consist chiefly of quartz in small crystals and crystalline aggregates; of crystallized dolomite, usually ferriferous; and of barite or heavy spar. In the Mollie Gibson and Smuggler mines the barite connected with the polybasite ore has often a flesh or pink color, which is due to a small amount of iron oxide.

Calcite is very common, and in many low-grade ores the dolomite of the unreplaced country rock forms the chief gangue material.

COMPOSITION OF ORES.

In order to get at the average composition of the ores of Aspen, nearly four hundred assays of shipments were obtained, representing ores from nearly every mine in the district. Each of these assays is a comparatively exact average of many tons of ore, this average being obtained before analysis by a mechanical process at the sampler. These different analyses were again added together and averaged. Since the ores have a wide range in point of elevation, varying from 10,800 feet and over in Tourtelotte Park to 7,400 feet or lower in the deep workings of the Mollie Gibson and Smuggler, the different analyses were tabulated and arranged according to elevation, in eighteen distinct zones, each zone being 200 feet in thickness. Thus the average analysis given for 7,400 feet includes all the ores from between 7,300 and 7,500 feet; that given for 7,600 feet included the ores from 7,500 to 7,700 feet, and so on.

Table showing average composition of Aspen ores, arranged according to elevation.

Elevation.	Silica (SiO_2).	Lime (CaO).	Iron (Fe_2O_3).	Barite ($BaSO_4$).	Zinc (Zn).	Sulphur (S).	Lead (Pb).	Silver (Ag).
Feet.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Oz. per ton.*
7,400	23.2	13.1	1.8	12.6	2.4	....	17.5	460.0
7,600	19.7	17.3	2.7	13.3	2.6	2.6	5.6	234.6
7,800	9.2	13.2	4.3	20.8	1.9	3.5	16.3	39.5
8,000	17.4	17.5	5.5	25.6	1.8	5.2	1.8	59.3
8,200	9.9	10.3	4.5	14.5	3.2	5.2	2.1	56.6
8,400	10.1	28.4	2.4	3.5	1.5	1.0	3.8	25.3
8,600	12.8	28.3	3.3	2.0	1.0	3.0	2.4	52.0
8,800	17.1	23.5	6.4	11.9	1.3	1.8	10.8	36.5
9,000	10.3	23.8	4.5	1.3	.4	.7	4.5	26.5
9,200	19.8	21.4	6.2	5.5	3.5	....	10.4	51.3
9,400	33.1	12.7	6.4	7.8	3.7	5.7	3.0	26.0
9,600	22.6	8.7	10.1	23.7	1.9	3.5	2.9	49.8
9,800	32.8	10.8	6.5	23.2	1.4	2.1	.8	71.9
10,000	23.0	11.1	8.9	24.2	2.1	.8	4.4	51.0
10,200	37.6	14.8	4.9	16.4	1.5	.9	2.4	35.6
10,400	27.3	7.5	10.3	21.8	3.2	6.6	6.7	62.5
10,600	52.5	....	....	30.5	....	....	....	27.3
10,800	28.5	12.8	4.4	31.0	Trace.	1.0	6.0	36.7

This table was primarily worked out with the idea that some definite order in the deposition of different minerals at different depths might be found, but the writer is unable to see any definite law. The table is valuable, however, for showing the average composition of the ores as derived from the tests of many hundreds of thousands of tons.

PARAGENESIS OF VEIN MATERIALS.

Microscopic examination shows that while the dolomite of the earlier period existed before the mineralization, yet among the vein materials ferriferous dolomite, quartz, and barite have ordinarily crystallized simultaneously. These minerals form large idiomorphic crystals, which are intergrown. Some of the sulphides seem to have been deposited at the same time with these gangue minerals, as is the case where crystals of pyrite are found interbedded in small dolomized areas which are surrounded by pure limestone, free from both magnesia and iron.

In perhaps the majority of cases, however, the sulphides seem to have crystallized at a very slightly later period than the barite. While the barite generally accompanies the ore, its presence is no indication of more valuable minerals, for many large and solid barite veins are found which are practically barren. This is the case, for example, with the large barite vein at the end of Yopsie tunnel. In Tourtelotte Park and in Smuggler Mountain, especially in the Mineral Farm mine, there are great masses of barite which contain very little valuable ore. Under the microscope the rich polybasite ore of the Mollie Gibson is seen to be composed partly of barite in interlocking, tubular crystals, among which are scattered bunches of polybasite, which are irregular in shape and have no suggestion of crystalline form. The polybasite does not follow definite zones, but is deposited between and around the barite crystals, showing that it crystallized at a slightly later period than did the barite. On Smuggler Mountain one of the chief ores is the so-called "crisscross spar," which is a barite in which is deposited tetrahedrite or tennantite in narrow seams. These seams are usually nonpersistent, and typically they form small isolated crosses, which give the ore its name. The arms of the crosses have the appearance of belonging to definite fracture systems, which have traversed the barite in directions independent of the planes of crystallization and cleavage, and therefore have opened at a period subsequent to the formation of the

mineral. Along these crevices it is apparent that the metallic sulphides have been introduced by circulating waters and have there been deposited. The analysis on page 224 of tennantite from the Mollie Gibson mine shows that it contains a large amount of silver sulphide, and explains why this crisscross spar invariably forms pay ore. The slight greenish stain which arises from the alteration of the sulphide is taken by miners as indicating the richness of ore throughout the district. Fig. 9 is a photograph of a particularly good specimen of this crisscross spar, kindly made by Mr. D. W. Brunton, of Aspen.

It seems evident that these crosses were formed along fractures made

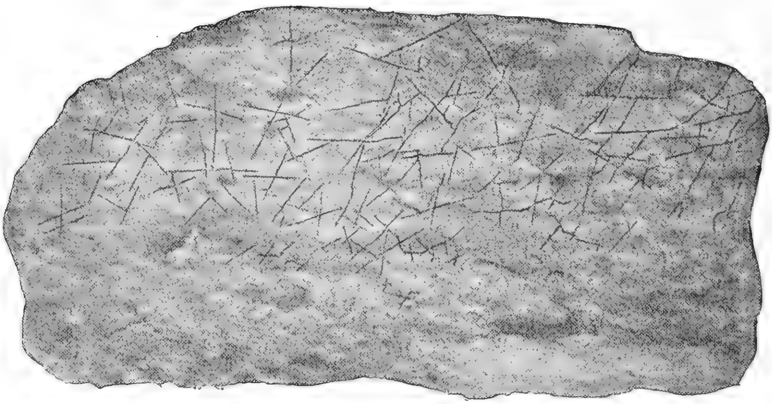


Fig. 9.—Crisscross spar.

in the barite since its formation. But as they are typically nonpersistent, the question arises as to whether the fractures themselves were nonpersistent or whether the sulphides have been deposited only at the intersection of two or more fractures. The writer at first was inclined toward the latter belief, but some phenomena of fracturing which point to the former alternative have been observed in the granites of Smuggler Mountain, not far from the place where the crisscross spar occurred. Certain zones of this granite have developed a gneissoid or slightly banded structure. Microscopic study shows that this change is due to shearing, and one effect of this shearing has been to bring about the formation of tiny fractures in the quartz grains. These fractures are intermittent, like the sulphide seams in crisscross spar.

They often form isolated crosses, and are most frequent in the center of the grain, from which they diminish toward the edges. Fig. 10 is a drawing of such a grain magnified 100 diameters.

Besides the gangue minerals which have already been mentioned calcite in its crystallized form is common in many ores. In every case where this has been studied microscopically it is found to be later than any of the ordinary gangue materials, and also later than the accompanying sulphides.

FIG. 10.—Microscopic fractures in granitic quartz.

Where it occurs in connection with barite, ferriferous dolomite, and quartz, it follows irregular spaces which are inclosed by the idiomorphic crystals of these minerals, and where, as in the Late Acquisition mine, galena occurs as a crust on the fragments of a breccia, this crust is covered with coarsely crystalline calcite which forms the immediate wall of the cavity.

LOCUS OF ORE DEPOSITION.

With scarcely a single exception the ore in the Aspen district is found along faults or faulted and fractured zones. Thus, for example, on Aspen

Mountain the ore occurs along the Contact, Aspen, Chloride, Bonnybel, Schiller, Pride, Mary B., and other faults. In Tourtelotte Park the chief mineralization has taken place along the Contact and Silver faults, but the ore shoots follow east-west and north-south fractures which cut these flat faults. On Smuggler Mountain ore is found along the Silver fault, but chiefly at its intersection with other faults and fractures which belong for the most part to the Della system; and in Queens Gulch and southward to the Little Annie mine, ore is found on the Castle Creek and its dependent faults. In all these cases the ore has evidently formed in place and has been deposited since the fault movement, for the breccia which was formed by this movement has been replaced and cemented by metallic minerals and by gangues, so that it very often forms the chief ore. In other faults ore is found broken by the movement along the fault in which it occurs, showing that the displacement took place, partly at least, subsequent to the ore deposition. Often, again, ore bodies which have formed in place along a fault have been disturbed by some subsequent movement, whose plane intersected the plane of the first.

The Silver and Contact faults, which lie close to the bedding, have been most important in determining the deposition of ore. These have been followed throughout the district as the most likely localities for discovering ore bodies, and thus the most productive zones run very close to them. It is not everywhere, however, that they are sufficiently mineralized to form ore. Indeed, this is not generally the case. The actual ore bodies are usually found at the intersection of these faults with some fault belonging to a different system. Along such a line of intersection the mineralization has taken place in continuous and definite shoots. The case of Smuggler Mountain may be cited, where nearly all the ore bodies which are extensive and rich have been formed at the intersection of the Silver fault with crosscutting faults, chiefly those which belong to the Della system. Along these intersections the shoots are extensive and continuous for long distances, while elsewhere both the Silver fault and the crosscutting breaks are ordinarily barren. In Aspen Mountain the best ore is found, both in dolomite and in blue limestone, at the intersection of small cross faults with the Aspen and Contact faults. In Tourtelotte Park the richest ore has been found in certain nearly vertical shoots which cut the Contact fault and run up continuously, in many cases, through the whole

thickness of blue limestone to the overlying shale, being highly mineralized, so as to form good ore throughout their whole extent. The Contact fault, away from the immediate vicinity of these fracture zones, also shows evidence of great mineralization, but the ore is generally low grade and can not be profitably worked.

EXTENT OF ORE DEPOSITION.

The surface extent of the district which has been actually largely productive of ore is practically identical with that of the faulted and uplifted region which is centralized in Tourtelotte Park and Aspen Mountain. With the disappearance of the faults and the appearance of comparatively unbroken strata the ore disappears, as might be expected from the fact which has just been pointed out, that ore invariably occurs along these faults. In the Hunter Park district, where there has been no faulting, there is also no mineralization, while in the Lenado district, where there are indications of a considerable amount of ore, the sections show a local uplift, apparently corresponding in nature with that of Tourtelotte Park. The main mineralization, however, is restricted to a small surface area, whose center is approximately in Aspen Mountain and Tourtelotte Park, and on whose borders are Smuggler Mountain on the one side and the deposits along the Castle Creek fault in Queens Gulch and southward on the other.

Within this uplifted and broken area ore has formed with an unknown vertical extent. The already existing mine workings have a great range in point of elevation, extending from the top of Tourtelotte Park down to the lowest levels of the Mollie Gibson and Smuggler, which extend nearly 1,000 feet below the bottom of the Roaring Fork Valley. This gives a vertical range of about 3,500 feet, and between these two points the ore is practically continuous. At the highest point the ore is found up to the grass roots, and at the bottom of the lowest workings there is still the same amount of mineralization. The table of analyses given on page 226 shows that in all this great range there is no important or persistent change in the composition or value of the ore, which indicates that it must extend downward for an indefinite but comparatively long distance, and that the original ore deposits extended far above the present surface, where they are

now revealed by erosion. It seems very probable, therefore, that this chief ore-bearing district has a greater vertical than lateral extent.

AGENTS OF MINERALIZATION.

From an economic point of view the deposition of metallic sulphides is the most important change which has come about in the rocks, but from a strictly scientific standpoint the formation of sulphides is only a minor phase in the general alteration which produced chiefly dolomite, quartz. and barite. Sulphides of the metals, where present, are always closely associated with these gangue materials, are generally inclosed by them, and occur along the same zones, these zones following faults and fractures which have evidently been watercourses. Microscopic study has shown that in places some of the sulphide was probably contemporaneous in formation with the magnesium and iron carbonate which replaced the limestone, forming ferriferous dolomite. The dolomite, quartz, and iron have been shown to be derived probably from heated and ascending waters, and this origin, therefore, is the one which is most applicable to the associated sulphides.

INFLUENCE OF DIFFERENT ROCKS ON ORE DEPOSITION.

The chief ore deposits occur in limestone or dolomite, in the majority of cases close to the Silver and Contact faults. There is some deposition of the precious metals in the lower formations, but not to any great extent. In Queens Gulch some ore has been shipped from the Silurian dolomite, and in the Princess Louise shaft in Spar Gulch a small amount was taken from the Cambrian quartzite. Near the Castle Creek fault in Queens Gulch even the granite shows evidence of mineralization, being altered and partly filled with gangue materials, such as quartz and ferriferous dolomite. Above the Leadville limestone some mineralization has been noticed in the red Maroon beds on Red Mountain, these beds being impregnated to a small extent with copper and silver, but not sufficiently to form ore bodies. Within the chiefly mineralized zone ore has been found extending through the whole thickness of the blue limestone, as in the Aspen, Durant, Camp Bird, Justice, and other mines, and in places nearly the whole thickness of Leadville dolomite is mineralized, as is the case in the Bonnybel mine

The generalization may be safely made, however, that most of the ore occurs throughout the district in the vicinity of the Weber shales, near the contact of these shales with the underlying rocks, and much of it actually occurs in this contact, which is formed by the Silver fault.

PROCESS OF MINERALIZATION.

The ore which occurs along faults and fractures extends into the apparently solid rock on both sides irregularly for a short distance. Microscopic study shows the process by which the metallic sulphides have replaced the original rock in these cases, for most of the ore is only a partially or even a slightly altered limestone or dolomite. In every case where examination was made of such ore the rock was found to be traversed by numerous reticulated fractures, along some of which microscopic faulting has taken place, all this showing the effects of great strain consequent upon the fault movement. Along these crevices the ores are in every case first introduced, and often this is the sole method of mineralization. Where the alteration has been greater, however, the metallic minerals penetrate from the fractures into the rock on both sides. The solutions seem first to travel between adjacent crystals of calcite or dolomite, and also along the cleavage planes of these minerals, this cleavage being especially well developed in consequence of the straining. In this way a still finer network is formed, which, by spreading and widening, has, in extreme cases, finally consolidated and formed a continuous mass of sulphide. There is no doubt that this is an actual process of replacement, the calcite or dolomite being taken up molecule by molecule and replaced by metallic minerals.

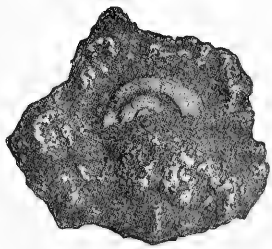


FIG. 11.—Fossil changed to native silver.

A further evidence of this process of replacement is the finding of fossils which are completely interbedded in the ore, or have been so changed as to form a part of the ore. Fig. 11 shows a mass of pure native silver, just as it was taken from the ore at the sampler in Aspen. In this silver part of a perfect fossil gasteropod is firmly embedded, and it is somewhat

remarkable that the shell is still made up of the aragonite of which it was originally composed. In the open cut near the Smuggler shaft the writer found a similar fossil gasteropod in hard ore. Both this fossil and the inclosing rock are largely made up of zinc and lead sulphides and carbonates, the composition of the fossil being exactly like that of the rock. The base of the fossil was embedded in hard ore like itself, but around the remainder the ore had been softened and so had fallen away, leaving the fossil projecting from the walls of the cut.

On the other hand, some of the metallic sulphides were deposited in preexisting cavities. In some of the ores on West Aspen Mountain, which occur along north-south faults, the galena is found as a crust which covers the fragments of a breccia, and often the mineralization has been so partial that irregular cavities are still left unfilled, the walls of which are coated with galena. In solid dolomite and limestone the sulphide often occurs in small nonpersistent seams, which have the aspect of veins, and the occurrence of argentiferous tetrahedrite or tennantite along crevices in heavy spar, forming the so-called crisscross spar, has already been described.

CAUSE OF THE PRECIPITATION OF ORES.

One of the most significant facts in regard to the occurrence of ore bodies is that they are generally found at the intersection of two faults, one of these faults usually dipping steeply, while the other is much flatter. If, as we have supposed, the solutions which brought the minerals were ascending hot springs, we may further suppose that these springs rose along the more steeply dipping or nearly vertical faults. If this is the case, the metallic sulphides were not deposited to any extent except at the intersection of these steep channels with others which lay flatter; but at such intersections there was some strong motive for precipitation, so that continuous and rich ore shoots were formed. The flatter-lying fault must also have been the channel of solutions, and the explanation is offered that by the mingling of solutions which had previously flowed along different channels the precipitation of metallic sulphides was brought about. It is not possible to decide without more careful study than has been made what the exact chemical processes may have been which brought about this result.

The most common method, however, by which sulphides are formed in nature and in the arts is by the addition of sulphureted hydrogen to soluble salts of the metals. If we suppose that the ascending solutions contained the metals in the form of these soluble salts, and that on reaching points where the channel along which they had risen was intersected by some different channel these solutions were mingled with others carrying an excess of sulphureted hydrogen, the ores would be precipitated just as we find them. These sulphureted waters, since they flowed along flatter faults, may have been derived more nearly from the surface. The proximity of most of the ore deposits to the Weber shales has already been mentioned. These shales contain much organic matter, the decomposition of which might readily have produced sulphureted hydrogen, which would be taken up by waters flowing through them. The occurrence of pyrite in shales is quite general, and often apparently results from the precipitation of iron brought in in the form of soluble salts by sulphur given off from decaying organic matter. In the Mollie Gibson mine water flowing from the shales contains much sulphureted hydrogen, and deposits native sulphur. This, however, may be in part derived from the oxidation of pyrite and other already existing sulphides.

ORIGINAL SOURCE OF METALS.

The beginning of the series of changes, of which the deposition of precious metals was one, consisted in the uplifting of the rocks over a limited area. This was accompanied by faulting, and along the channels afforded by these faults there arose mineral-bearing solutions which deposited their burden under the conditions which have been described. The cause of the peculiar, domelike uplift has been suggested to be possibly a body of eruptive rock which for some reason accumulated immediately below this area. The connection of eruptive rocks with ore deposits, not only in Colorado but throughout the world, is well known, and does not need any comment. In accordance with the generally accepted views of hot-spring action, we may suppose that surface waters, on sinking, came in contact with a body of heated rock which underlay the uplifted area, and that in this way the water itself became heated and dissolved some of the rock materials. Eruptive rocks usually contain barium, although this

element is rare in sedimentary beds. It is often found in the feldspars, and forms an essential constituent in one variety—hyalophane. Sandberger[1] has shown that most of the metals found in veins as sulphides are present in eruptive rocks, probably as original constituents, especially in the dark-colored silicates, such as biotite, hornblende, and olivine. The heated waters would then be propelled upward, as is actually the case in all hot springs, and, finding their readiest channels along the faults which traverse the uplifted area, would follow them and deposit their contents where conditions were favorable.

CHANGES IN ORE SINCE DEPOSITION.

MECHANICAL CHANGES.

Since the deposition of the ore many of the faults have continued moving and some new ones have come into existence. In this way ore which has been formed in place along a fault has often been broken, and even triturated, by subsequent movement along the same plane. This phenomenon is continually shown along the Silver fault in Smuggler Mountain and many other mineral-bearing faults Where new faults have developed since the ore deposition the ore bodies have often been displaced and their parts more or less widely separated. The displacement by the Clark fault in the Smuggler and Mollie Gibson mines is an example of this. Along such faults the ore occurs in the breccia, having been dragged up from the solid mass. The ore at Lenado is supposed to be a larger example of this same process, the broken-up condition showing that it has been subjected to great movement since its deposition

CHEMICAL CHANGES.

Formation of native silver.—Native silver is of very common occurrence in the ores immediately below the oxidized zone. In the rich polybasite ore of the Mollie Gibson and Smuggler it often forms a very important constituent. This native silver is generally associated with the carbonaceous Weber shale. It is sometimes solid and massive, but very often spun into wires

[1] F. Sandberger, Untersuchungen über Erzgänge, 1882.

and delicate threads, which occur in crevices and vugs. In one case in the Mollie Gibson such a vug was a foot or two in diameter and was completely and closely festooned with threadlike silver in so large an amount that several small ore bags were filled with it.

The rich ore, consisting of barite and polybasite, with tennantite, undergoes a change by which the sulphides disappear, their places being taken by native silver. This process is accompanied by a reduction, so that the ore becomes crumbling and consists essentially of barite held together by silver. It is along fractured zones and watercourses that this ordinarily takes place, and usually also in the neighborhood of the carbonaceous Weber shales. Along the Clark fault in the Mollie Gibson some of the breccia has been cemented by native silver which is apparently comparatively recent in deposition. The process is not clearly understood, but it is probable that the organic matter in the shales has operated in the reduction, and it is clear also that circulating waters have probably been instrumental. In the concentrating works at Aspen, where ore is crushed and separated by means of ordinary cold water, certain iron parts of the apparatus become coated with native silver precipitated from the water which flows over them. This shows that ordinary surface waters have power to dissolve and carry away silver, which they deposit under favorable circumstances. In the highly oxidized ores near the surface, however, silver is not usually found native, but is apparently altered to one of its salts.

Oxidation of ores.—For a variable distance below the surface the sulphide ores have been altered by the effects of surface action, and assume other forms. In the highest mines in the district—in Tourtelotte Park—the ore is all oxidized, while in the workings of Aspen and Smuggler mountains the transitional stages of oxidation are all seen, and in the lower workings of the deep mines the original sulphide condition prevails. On oxidation, the ore loses cohesion and becomes brittle or crumbling, the altered minerals generally assuming a pulverulent form. All the sulphides thus disappear and are replaced by oxides, sulphates, and carbonates. The barite, however, does not change. An analysis of the typical oxidized barite ore from the Buckhorn No. 2 mine, in Tourtelotte Park, was made by Dr. H. N. Stokes, of the Survey, with the following result:

Analysis of oxidized ore from Buckhorn No. 2 mine, Tourtelotte Park.

	Per cent.
Silica (SiO_2)	1.90
Titanium dioxide (TiO_2)	Trace.
Carbon dioxide (CO_2)	10.69
Sulphur trioxide (SO_3)	16.96
Sulphur (S)	.30
Silver oxide (Ag_2O)	.29 (=.27 Ag, silver).
Copper oxide (CuO)	.18 (=.14 Cu, copper).
Lead oxide (PbO)	38.46 (=35.71 Pb, lead).
Alumina (Al_2O_3)	.43
Ferric oxide (Fe_2O_3)	.43
Manganese oxide (MnO)	Trace.
Baryta (BaO)	22.11
Strontia (SrO)	.46
Lime (CaO)	7.74
Magnesia (MgO)	.16
Water (H_2O) Below 110°	.05
Water (H_2O) Above 110°	.33
	100.49
Less O=S	.15
	100.34

The following table represents the approximate composition of the ore under the assumption that barium and strontium are present as sulphates only, that the small amount of sulphur exists as sulphide of silver and lead, that the remaining sulphur trioxide is in lead sulphate, and the rest of the lead exists as carbonate. The carbon dioxide left over just suffices to form calcium carbonate from the lime:

Approximate composition of the ore.

	Per cent.
Barium sulphate ($BaSO_4$)	33.7
Strontium sulphate ($SrSO_4$)	.8
Lead sulphate ($PbSO_4$)	19.1
Lead carbonate ($PbCO_3$)	26.7
Lead sulphide (PbS)	2.2
Calcium carbonate ($CaCO_3$)	14.3
Silver sulphide (Ag_2S)	.3
	97.1
Other constituents	3.5
	100.6

This analysis shows that the lead at least, which is the most conspicuous metallic constituent, is contained in the oxidized form both as sulphate and as carbonate, chiefly the latter.

Sulphate of magnesia.—On the walls of abandoned drifts in the mines there form under favorable circumstances long, silky, and hairlike masses of crystals, sometimes several inches long. These are in places very abundant and beautiful. They have a bitter taste, and analysis shows them to be composed essentially of hydrous sulphate of magnesia, probably epsomite. On the walls of quarries or open cuts in the ore a drier white coating forms, which is composed of sulphates, chiefly the sulphate of magnesia. This sulphate probably originates from the decomposition of sulphides, the products of which form sulphate with magnesium solutions.

Sulphur.—At Lenado, on the dump of the Leadville mine, a thin crust of yellow sulphur was noted forming on the outside of the sulphide ores. There was also a noticeable smell of sulphur dioxide given off, and at the same place certain white sulphates were found.

Bog manganese in caves.—In the Best Friend mine, in Tourtelotte Park, there is evidence of a fissure which at some recent time existed along the Contact fault, and which locally opened out into considerable caves. In one of these caves, which was originally over 20 feet high, and which was subsequently filled by cave sediments, the lowest layer of material is very fine grained and black, and a sample gave on analysis 45.86 per cent of manganese oxide, with 12.83 per cent of iron oxide. This manganese was evidently introduced by surface waters, and was precipitated by essentially the same process as that which forms manganese in bogs at the surface. The ores of silver and lead contain small amounts of manganese, the analysis of polybasite ore by S. H. Pearce[1] showing an average of 1.03 per cent of manganese carbonate, while that of the oxidized ores in Tourtelotte Park by Dr. Stokes gives only a trace. It is probable, therefore, that the manganese is leached out of the ores in the process of oxidation, and that it may be precipitated in a concentrated form under favorable conditions, such as the bottom of this cave presented.

Formation of gypsum.—On the northeast side of West Aspen Mountain there is an extensive alteration of the Weber limestone to gypsum. Tunnels

[1] Am. Jour. Sci., July. 1892, 3d series, Vol. XLIV, p. 17.

which run into the hill in this vicinity show the Weber rocks to be much broken up between the glacial drift and the Pride fault. Ordinarily the brecciation is greatest close to the fault and at the other end close to the surface, while in the middle the rock is not so much broken. This seems to show that the brecciation was due partly to the fault movement and partly to the overriding of the glacier. Throughout the whole rock the main feature is the extraordinary alteration to gypsum. Vein gypsum (selenite) forms in every crevice and chink, and many of the limestone bowlders are also completely altered to gypsum while still preserving the structure of limestone. Such bowlders show ordinarily under the microscope that the gypsum has actually resulted from the alteration of calcite. Thin sections show mainly gypsum in coarse, interlocking crystals, while scattered throughout is considerable calcite in coarsely granular aggregates or interlocking crystals. The calcite forms small, irregular masses with well-defined boundaries, or occurs in small grains more or less thickly disseminated in the gypsum; or, not infrequently, it is concentrated into isolated rhombohedra, recalling the phenomena attendant upon the silicification of limestone. The alteration of the carbonate to sulphate is thus shown in its various stages. The Castle Creek fault, from the point where it crosses Woody Creek after traversing Red Mountain, is continuously marked for several miles down the valley by a zone composed largely of gypsum. From a thick deposit which outcrops near Woody Creek along this fault a sample was taken, which was a fine, white powder consisting almost entirely of gypsum, as seen by the following analysis:

Analysis of sample from deposit along Castle Creek fault, near Woody Creek.

	Per cent.
Silica (SiO_2)	1.46
Carbon dioxide (CO_2)	2.29
Sulphur trioxide (SO_3)	40.74
Lime (CaO)	31.86
Magnesia (MgO)	.44

The gypsum on Aspen Mountain is evidently post-Glacial, since it has altered and cemented a glacial breccia. Along Woody Creek its distribu-

tion shows that the change has been brought about by waters which circulated along the Castle Creek fault. It is likely that soluble sulphates, brought up by hot-spring or other waters, were precipitated when coming in contact with carbonate of lime, as gypsum, and thus a true replacement was effected.

Leaching of rocks.—Along the underground channels the effects of circulating waters are seen in the softening of the rocks through which they pass. The process consists in the leaching out of the more soluble constituents and in the reduction of the comparatively insoluble portions, by removal of the cement, to a clayey form. Thus in the vicinity of the Castle Creek fault in Keno Gulch granite is altered to a kaolin which contains grains of residual quartz. Along the Lenado fault in the Aspen Contact and Leadville mines the Cambrian quartzite is softened for some distance so as to form a white clay, which grows coarser and more solid as the distance from the fault increases. This clay is often called by the miners "porphyry," but the process of its formation seems to be the removal of some of the silica, especially the secondary cement between the quartz grains, by circulating waters. When the cement is removed the rock disintegrates and forms a clay.

The alteration of limestone and dolomite by surface waters along faults and fracture zones is seen throughout the mineral-bearing district. Thus along the Silver fault in certain mines the limestone becomes altered, so as to be mistaken for Weber shales, although the Weber rocks themselves are not soft and claylike except where they have been acted upon by these surface waters. At one locality in the Argentum-Juniata mine the dolomite along watercourses was observed to be altered completely for some distance to a soft clay, which is sometimes bleached to a yellow color, and goes among the miners by the name of "talc" or "shale." The stages of transition between the solid dolomite and the clay show sufficiently the origin of the latter.

In the hard Weber limestones in several places the same phenomena were observed. In the Clark tunnel at Lenado two samples were taken for analysis from the Weber rocks, one being of limestone which was partially softened and the other of limestone which was completely softened and also bleached. These analyses are given as Nos. 2 and 3 in the following

table. No. 1 is the partial analysis of a fresh Weber rock, which chances to be a nearly typical dolomite:

Analyses of limestones from Weber formation in Clark tunnel at Lenado.

	1.	2.	3.
SiO	12.12	18.67	55.98
Al_2O_3	3.97	8.31	20.22
Fe_2O_3	2.06	2.60	7.46
CaO	25.63	36.93	3.05
MgO	15.97	.72	1.01

From these analyses it appears that the process of disintegration is a removal of the soluble material, chiefly calcium and magnesium carbonates, and the consequent concentration of the silica and alumina, the result being an impure clay.

LIST OF MINERALS.

Following is a list of minerals thus far recognized megascopically in the immediate vicinity of Aspen:

Sulphides: Galenite, sphalerite, pyrite, polybasite, tetrahedrite, tennantite, chalcopyrite, argentite, bornite, pyrargyrite.

Sulphates: Barite, gypsum, anglesite, epsomite.

Carbonates: Calcite, aragonite, dolomite, siderite, cerussite, smithsonite, azurite, malachite.

Oxides: Hematite, limonite, wad, minium (?), melaconite (?), cuprite (?).

Silicates: Calamine (?), chrysocolla.

CHAPTER V.

SURFACE CHANGES SINCE ORE DEPOSITION.

AMOUNT OF EROSION.

Since the beginning of the period of deformation in the Aspen district, which gave rise to various physical and chemical changes, of which ore deposition is among the most interesting, an enormous amount of erosion has taken place. Previous to the Cretaceous uplift there extended over the whole of this district a thickness of at least 15,000 feet of sediments overlying the granite. That this is true is shown by the fact that these sediments still actually exist in that part of the district which lies west of the Castle Creek fault. East of the fault, however, in the metalliferous district, the rate of uplifting was vastly greater than farther west, bringing the granite and the lower sedimentary beds to the position they now occupy on Aspen Mountain and Tourtelotte Park; and the relief resulting from this uplift caused accelerated erosion, which from that time to the present has removed the sedimentary beds down to the granite, a thickness, as stated, of over 15,000 feet.

DIFFERENTIAL EROSION.

Most of the topographical features of the district have been largely influenced in their formation by the structure of the underlying rock. Thus it is noticeable everywhere that erosion of shales and sandstones has been greater than that of the more resistant granite, quartzite, and solid limestones. For this reason the valleys of Roaring Fork and Woody Creek widen immediately after emerging from the granite upon the softer sedimentary beds; and Aspen Mountain, where an uplift has produced a peculiar underground structure differing from the rest of the district, stands out also as a peculiar topographical form, the ridges of East Aspen and West Aspen mountains being formed by the resistant granite, quartzite, and dolomite, and the broad depression between them resulting from the greater erosion

of the shales and porphyry which are contained in the Aspen Mountain syncline. Erosion of shales under the same conditions has formed the shallow basin of Tourtelotte Park.

INFLUENCE OF FAULTS.

The faults also, as well as the folds, have greatly influenced the topography. Gulches following the outcrops of faults are very common—for example, the upper part of Queens and Spar gulches, and Copper Gulch. The reason for the formation of gulches along fault lines appears to lie partly in the fact that fault zones are in brecciated material, which is more easily eroded than the surrounding rocks. It is notable, however, that in Spar Gulch and Queens Gulch, only the upper part of the gulch lies in the fault, the lower part diverging from it to join some larger channel. These fault zones are channels of underground water, which occasionally rises to the surface as springs, and in Queens Gulch such a spring, which is really a small underground stream, rises along the Castle Creek fault, and it is from the erosion of this water that the gulch appears to have been chiefly formed.

GLACIATION.

Most of the topographical forms have been influenced by glacial action. Glacial drift is found over the whole district, although often locally stripped off by more recent erosion. In the river beds the glacial deposits are somewhat modified, and this rearranged drift forms the floor of the larger valleys, such as Roaring Fork and Hunter Creek. On the high hills, however, the drift exists as unmodified moraine. On Ajax Hill, which lies between Roaring Fork and Castle Creek, and above Aspen Mountain and Tourtelotte Park, there is found all along the southwest side, near the summit, a broad bench, of glacial origin, carved in the bed rock. This bench is ordinarily covered with morainal material, so that there are no outcrops. The material consists of a granitic matrix containing quartzite and granite bowlders, none of which are of very great dimensions, and is comparatively uniform, even when the underlying rock is dolomite and limestone. At intervals, however, this bench has been cut through by post-Glacial erosion, and the covering of drift has been stripped away. Thus strongly marked gulches are formed with bare rock on both sides. Toward the south the bench widens out, and the topography of the whole

GLACIATED SURFACE ON RIDGE BETWEEN ROARING FORK AND CASTLE CREEK VALLEYS.

country suggests profound glaciation. Pl. XXXIII is a view looking south from this hill toward Difficult Creek and the headwaters of the Roaring Fork. In the foreground is a broad, gently sloping bench, which, at the point from which this picture was taken, has an altitude of nearly 11,000 feet, and thus is 2,500 feet above the bottom of the Roaring Fork Valley, a short distance away. The details of topography of this bench present a typically glaciated aspect. From a favorable point of view it presents a rude resemblance to a plowed field, being marked by straight and parallel furrows set a short distance apart, so that ridges and furrows alternate. The ridges are sometimes composed of bed rock, but more commonly of loose morainal material; and the higher ones are often carved into lenticular forms, suggesting roches moutonnées.

On the opposite side of Roaring Fork Valley there is also continued evidence of glaciation. The granite hills which rise east of Smuggler Mountain, between Hunter Creek and Roaring Fork, have all been planed down by glacial action, and frequently carry morainal material. These mountains are over 11,000 feet high, and therefore more than 3,000 feet above Roaring Fork Valley. On the top of Smuggler Mountain proper, which is 10,000 feet high, the thickness of moraine, as shown in the Park-Regent and Bushwhacker shafts, is about 400 feet, but this drift is perhaps the moraine of the Hunter Creek glacier, which was smaller and of later date than the general ice sheet.

Red Mountain appears from the southeast and southwest sides, from which it is best seen, as a hill of bare rock, the outcrops of which can be seen continuously all the way from the top to the bottom. Around the base of this mountain is morainal material, the upper limit of which is very strongly marked. The top of the mountain, however, which is comparatively flat, presents no outcrops, but is heavily covered with morainal material, which is chiefly of granite, with some quartzite. On the very top of the hill, also, there exists a well-marked stream bed, with terraces on its sides, which have been cut partly in the drift and partly in the bed rock, and evidently resulted from the action of some swift glacial torrent. There does not appear to be a trace of this stream bed or of the morainal material on the mountain side.

Between Hunter and Woody creeks all the highest country is carved into typical glaciated forms. The topography, as seen on the map, is

comparatively smooth, showing long, low ridges or drumlinoidal hills, with gently curved or straight furrowlike depressions, which run in a general east-west direction. Over this surface there is a heavy morainal covering, consisting chiefly of granite and quartzite, none of the bowlders being very large. In places there are well-marked lines of moraine, with larger bowlders, and in these places the drift is often as much as 100 feet thick. Pl. XXXIV shows this glaciated topography, with the valley of Hunter Creek on the right and the summits of the Sawatch Range in the distance.

DIRECTION OF ICE MOVEMENT.

Judging from the transportation of material and from the direction of the furrows which the ice has impressed upon the topography, the glacier had a general movement toward the west, away from the Sawatch. On Red Mountain the drift consists mainly of granite and quartzite, which must have been carried in a westerly direction across the intervening Hunter Creek Valley. In the Roaring Fork Valley there are large quantities of granite in the moraine, and granite bowlders are especially frequent below Red Butte on the flanks of Red Mountain.

DIMENSIONS OF ICE SHEET.

The ice sheet overrode all the hills and valleys in this district, and its movement was apparently not influenced by the topography. The hills over which it moved now rise 3,000 feet above the broad Roaring Fork Valley, and the transportation of material as illustrated on Red Mountain shows that the ice did not move down into the valley, but along the mountain tops parallel to it. If this valley were as deep at the time when this great glacier existed as at present, the thickness of ice must have been at least 3,000 feet. This ice sheet, however, disappeared at a comparatively ancient period, as is shown by the great effects of subsequent erosion, for on Red Mountain and other localities the drift has been completely stripped away from the mountain sides, leaving a bare and apparently unglaciated surface.

ROARING FORK GLACIER.

In the last stages of the Glacial period the ice shrunk to comparatively small dimensions, and existed only in local glaciers, which ran in the pres-

GLACIATED SURFACE BETWEEN HUNTER CREEK AND WOODY CREEK.

GLACIAL VALLEY OF ROARING FORK AND REMNANT OF PRE-GLACIAL VALLEY.

MEANDERS OF ROARING FORK.

ent river valleys. Valleys in granite show best the effects of the carving of these local glaciers, since granite is resistant and homogeneous, and these valleys present a uniform U-shaped structure. For this reason the valleys of Hunter Creek and Roaring Fork offer most complete records.

About 10 miles above Aspen, and not far from the summit of the Sawatch, the valley of the Roaring Fork is wide and shallow, with gently sloping walls of granite and a granite floor, polished and carved into irregular, rounded forms. Through the middle of this broad glacial valley there winds a steep, narrow gorge or canyon, which in places is almost obliterated and in other places has steep walls which reach probably 200 feet in height. The tops of these canyon walls form part of the general floor of the glacial valley. In places this canyon is wanting, the broader valley being locally deeper and removing all traces of it, while in other places it becomes quite conspicuous. It becomes progressively fainter, however, as the distance from the head waters and the depth of the broad glacial valley increase, and entirely disappears 9 or 10 miles above Aspen. This gorge is evidently the remains of a pre-Glacial canyon of the Roaring Fork, of which only traces are left, below the plane of glacial action. Pl. XXXV gives a general view of the broad, shallow glacial valley, with the pre-Glacial canyon represented by the V-shaped depression on the right.

Downstream from this bare granite area there is an increasing amount of ground moraine, the bowlders being very large, and about 5 or 6 miles above Aspen comes a frontal moraine which crosses and fills up the valley. Just back of this moraine is a little level space, composed of fine lake sediments, and capable of some cultivation, and in the middle of this is a small pond, about 200 feet across. This is evidently the bed of a small lake which was dammed up by the frontal moraine until the stream cut through and drained it.

Below this moraine the bottom of the valley is remarkably smooth and level to about a mile above Aspen, where there occurs the rear wall of a strongly marked terminal moraine, whose front wall comes quite down to Aspen. Between this moraine and the one last described there is evidence of a glacial lake which existed immediately after the disappearance of the Roaring Fork glacier. The valley bottom is a series of broad, flat meadows, with patches and islands of coarse morainal material. Most of these meadows are wet, and there are also extensive swamps. In

several of these there are small ponds of standing water, which are being rapidly converted by encroaching vegetation into swamps. Throughout this soft lake sediment the river has carved very beautiful meanders, as may be seen in the accompanying plate (Pl. XXXVI). These meanders have met and cut off repeatedly, some of the cut-offs being complex, double, or triple, and in the plain on the opposite side from that where the river now is can be seen the scars of old meanders, showing that the stream has swung across the whole valley and worked over the sediments pretty thoroughly since the Glacial era.

Below the terminal moraine which is found just above Aspen the valley widens out into a broad, level plain, through which the streams of Roaring Fork, Castle, and Maroon creeks have cut post-Glacial gorges. The glacial material in the bottom of this valley is probably in places several hundred feet thick, and is composed of coarse morainal material, which has been worked over by water action so as to possess a rude stratification. In some localities there is also a deposit of finer, sandy material, more perfectly stratified. On the sides of this valley, as is best seen on Red Mountain, are broad terraces carved in the bed rock, but sometimes strewn with glacial material. On Red Mountain these terraces are chiefly two in number, and on the upper one some agriculture has been carried on. Here the terraces are carved in the red Maroon sandstones, but farther down the valley, on the west side of Castle Creek fault, they are well marked in the soft Cretaceous rocks. These terraces must have formed since the disappearance of the main ice sheet, for if they had existed previously they would have been scored away by the glacier. The highest and most strongly marked terrace on Red Mountain is 400 or 500 feet above the present valley, and so can not be accounted for by ordinary stream action. The terraces, therefore, probably indicate the shores of a long, narrow lake, which filled up the Aspen Valley near the close of the Glacial period. The same broad valley is continuous for several miles downstream below Woody Station. Near this point a prominent hill, capped with basalt, juts out into the valley, so as to reduce it to comparatively narrow dimensions. This hill must have constituted a continual barrier to glaciers, and here toward the close of the Glacial period there may have accumulated a wall of ice or a moraine which backed up water so as to form a lake. The terraces on Red Mountain are shown in Pl. XXXVII.

TERRACES ON RED MOUNTAIN.

MORAINE OF HUNTER CREEK GLACIER, ON RED MOUNTAIN.

HUNTER CREEK GLACIER.

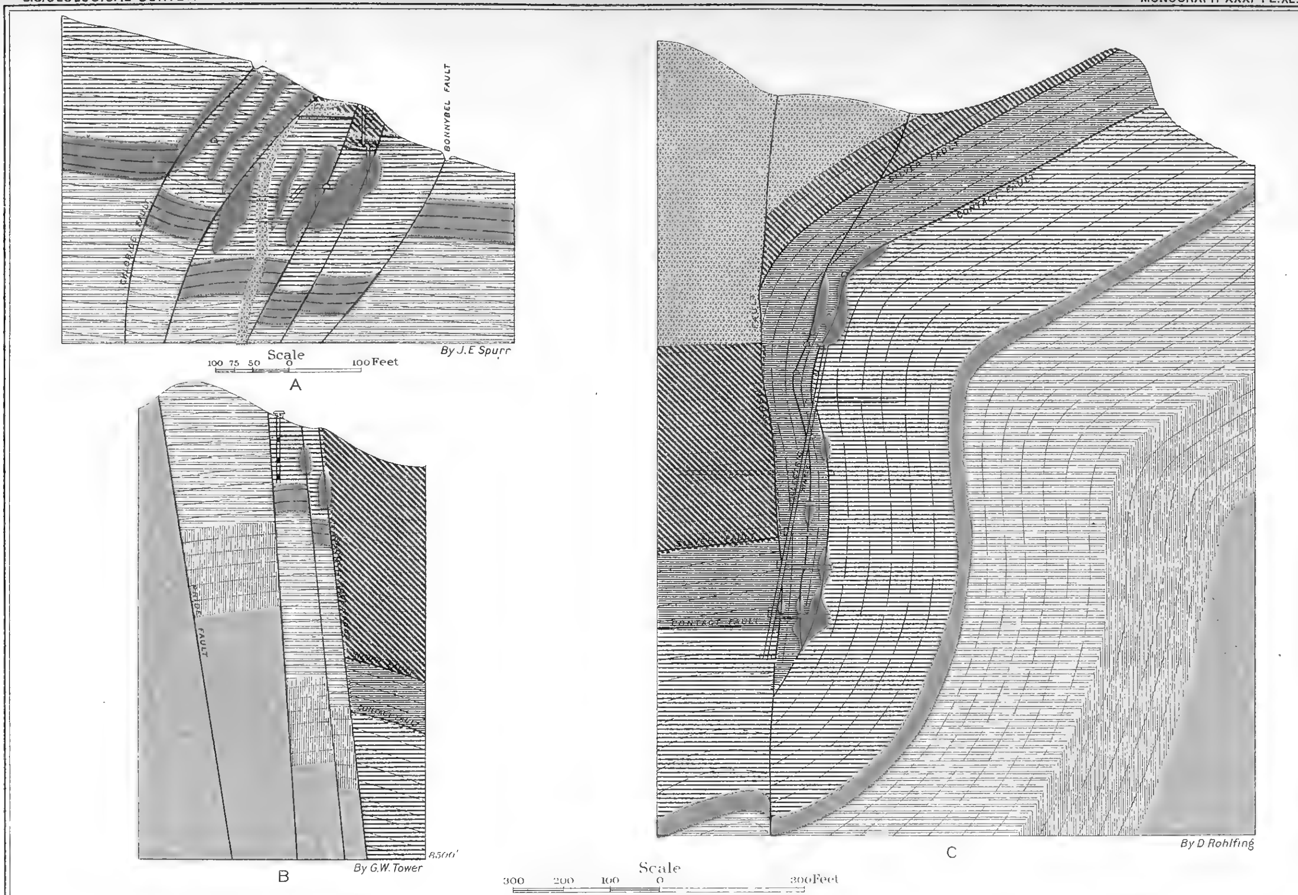
The local glacier which occupied the Hunter Creek Valley has left its traces in the lateral moraine which lies at the base of Red Mountain. Pl. XXXVIII is a view of the southeast side of this mountain, taken from across the Hunter Creek Valley. At the base is the lateral moraine of the Hunter Creek glacier, containing many huge bowlders, which are chiefly of granite. The upper limit of this morainal material is sharply defined, and above this there is no evidence of glacial action until the top of the mountain is reached, the rocks being all comparatively bare. On the very top, however, is the ground moraine of the earlier and more extensive ice sheet.

The Hunter Creek glacier carved for itself a typical U-shaped valley, which may be seen in Pl. XXXIX. This view is up the valley, with the summits of the Sawatch in the distance. At some distance up the valley is seen a cliff projecting boldly and precipitously into the valley, and this seems to be a remnant of the pre-Glacial canyon. The valley does not extend westward farther than the highest terrace on Red Mountain, which is 400 or 500 feet above the Roaring Fork Valley, where it stops suddenly. This may be best seen by consulting the special topographical map of Aspen. The ending of the valley at this level shows that the Hunter Creek glacier flowed into the lake which covered the Roaring Fork Valley at a time when the latter stood at its highest level, as marked by the uppermost terrace. When the waters were drawn off from this lake, Hunter Creek found its way into the waters of Roaring Fork, turning at right angles to its normal course, and rushing down precipitously over the sides of the deeper Roaring Fork Valley. In this way it actually descends about 500 feet in a horizontal distance of 2,500 feet, while above this turning point its course in its east-west glacial valley is very sluggish. In this rapid descent it has carved a rocky and often precipitous gorge in the Maroon sandstones and in the drift. The existence of remnants of pre-Glacial canyons, both in Roaring Fork and in Hunter Creek, shows that these were both stream channels previous to the advent of the ice sheet, and it is probable that their pre-Glacial streams ran at approximately the same level. In the case of Roaring Fork, however, the local glacier has carved out a valley at least 500 feet deeper at Aspen than that of Hunter Creek.

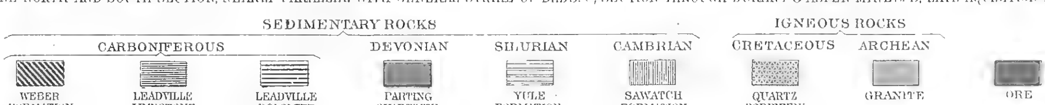
RÉSUMÉ OF GLACIAL ACTION.

The evidence goes to show that at a relatively remote period the Aspen district was covered by a great ice sheet, which moved west, away from the Sawatch range, over hill and valley. This glacier carved the surface into typical glaciated, rounded, and drumlinoid forms, and excavated the softer shales and sandstones more than the resistant granite. The débris of this great glacier is found on top of the highest mountains in the district. Subsequently this ice sheet shrank into separate glaciers, which followed the valleys of preexisting streams and in large measure carved them into their present forms. These valley glaciers, by erosion along their sides, caused a steepening of the mountain slopes, and so brought about the removal of most of the previously accumulated drift. It thus happens that at present the sides of the mountain often appear bare and unglaciated, and the drift of the earlier glaciation is found only on the summit. At a still later stage in the glaciation the valley of Roaring Fork was occupied by a long, narrow glacial lake, which probably resulted from some temporary dam. During most of its existence the surface of this lake was 400 or 500 feet above the present town of Aspen, and into it the dying glacier of Hunter Creek and its waters emptied.

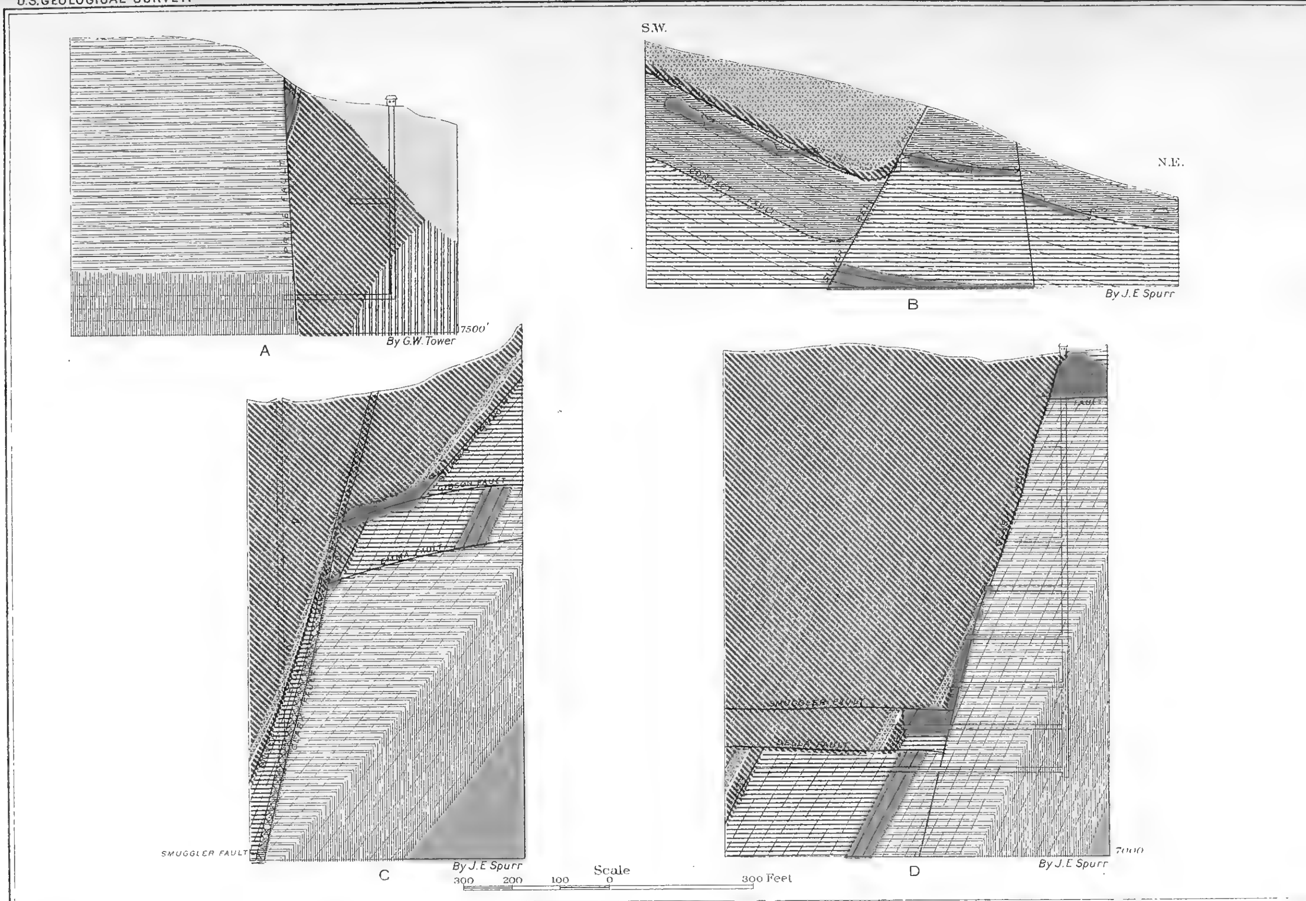
VALLEY OF HUNTER CREEK.



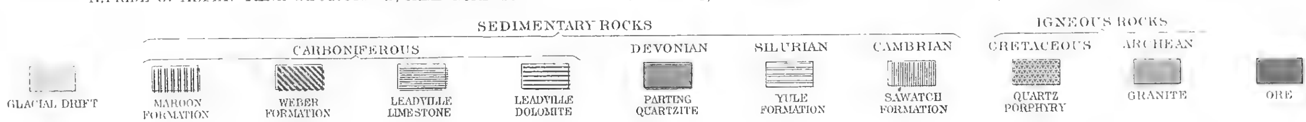
A, BONNYBEL MINE NORTH AND SOUTH SECTION, NEARLY PARALLEL WITH GENERAL STRIKE OF BEDS. C, SECTION THROUGH DURANT & ASPEN MINES. B, LATE AQUISITION MINE SECTION.



JULIUS BIEN & CO. N.Y.



A, PRIDE OF ASPEN MINE SECTION. B, CAMP BIRD IOWA CHIEF SECTION. C, MOLLY GIBSON MINE SECTION. D, SMUGGLER SHAFT SECTION.



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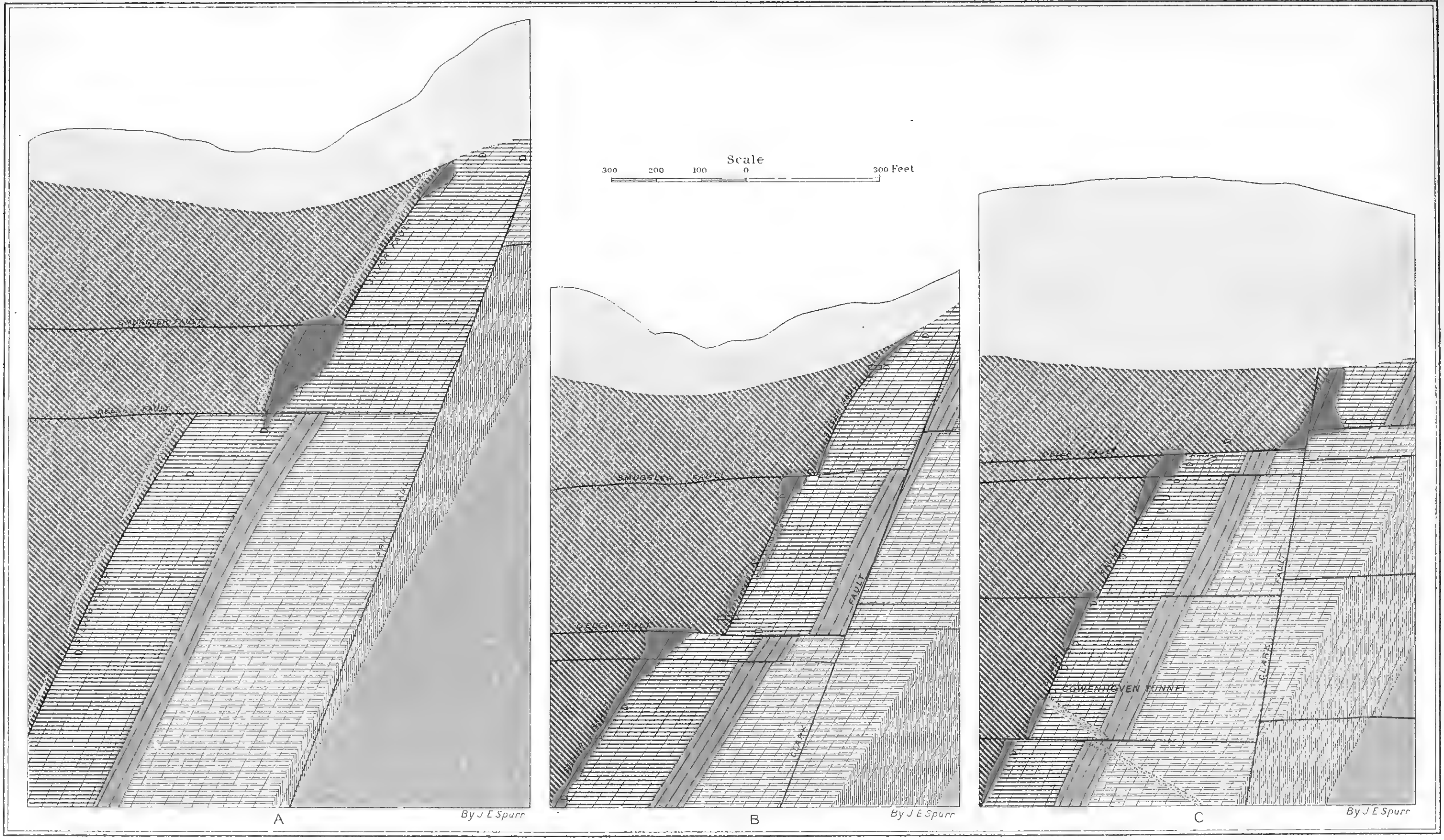
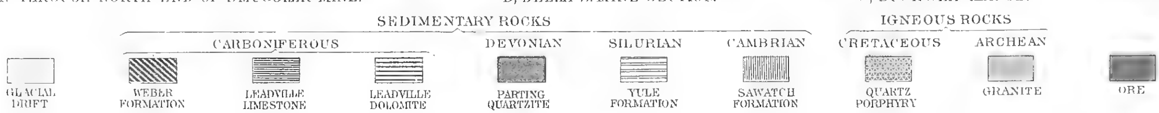


A, SECTION THROUGH NORTH END OF SMUGGLER MINE. B, DELLA S. MINE SECTION. C, BUSHWHACKER-PARK REGENT MINE SECTION



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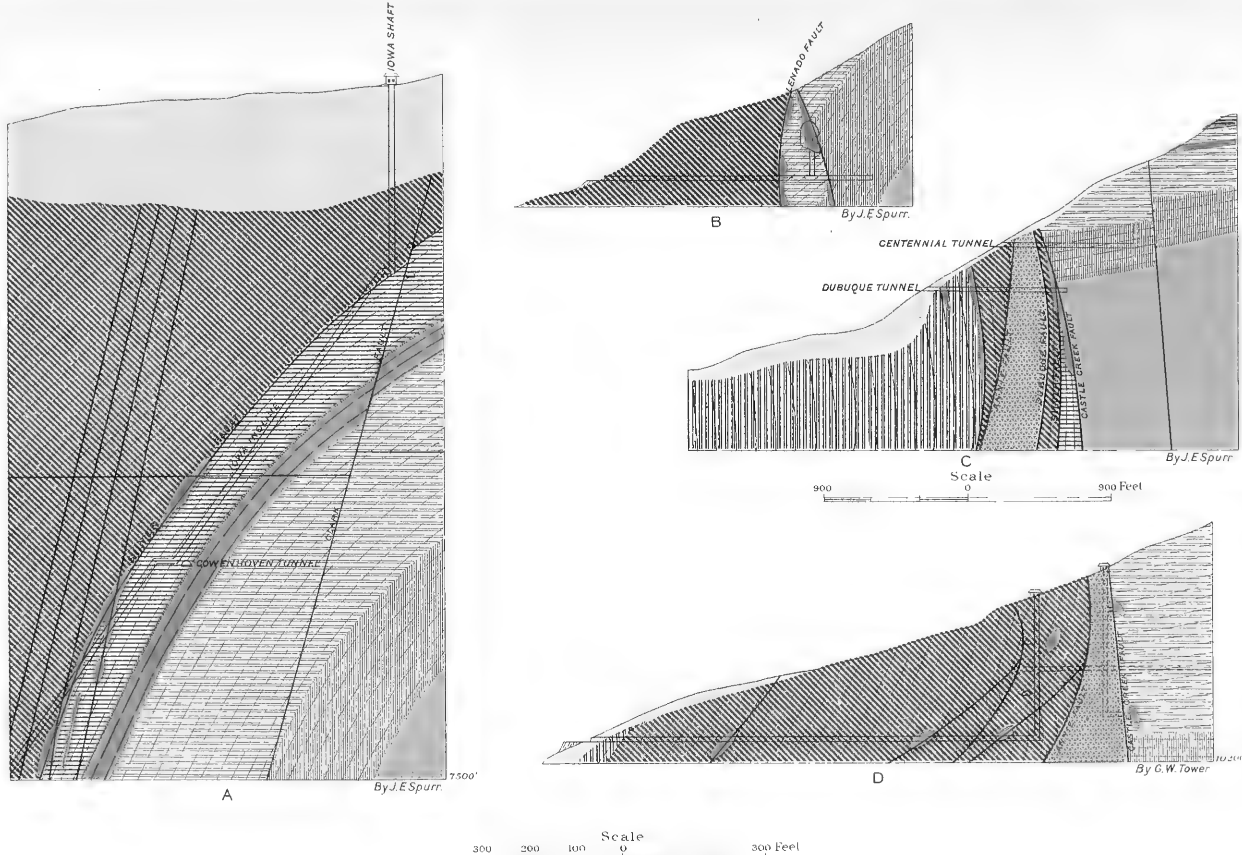

A, SECTION PARK REGENT MINE. B, SECTION ASPEN CONTACT MINE, LENADO. C, SECTION DUBUQUE MINE. D, SECTION LITTLE ANNIE MINE

SEDIMENTARY ROCKS: CARBONIFEROUS — MAROON FORMATION, WEBER FORMATION, LEADVILLE DOLOMITE; DEVONIAN — PARTING QUARTZITE; SILURIAN — YULE FORMATION; CAMBRIAN — SAWATCH FORMATION

IGNEOUS ROCKS: CRETACEOUS — QUARTZ PORPHYRY, DIORITE PORPHYRY; ARCHEAN — GRANITE

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APPENDIX.

MEASUREMENT OF FAULTS.

According to the definition given by Dana, "faults are displacements along fractures." Whenever the rocks of the earth's crust are subjected to strain, fractures take place in them as they would in any other body under similar conditions, and the different parts of the rock tend to move past one another along these fractured planes, seeking relief from the strain and accommodating themselves to new conditions. In this movement one part of the fractured rock mass may move upon the other in any direction—up, down, sidewise, or obliquely—according to the conditions, which are different in each instance. There is, so far as I know, no law governing the direction of movement in faults which is of any use in geological diagnosis. Naturally when there is any preexisting plane of weakness of the rock which is subjected to strain the movement generally takes place along this plane, and hence in sedimentary beds it is probable that movements along the bedding planes constitute the commonest variety of faults. Inasmuch, however, as the beds in disturbed districts lie in every conceivable position, the probability just stated does not give any clue to the average attitude of faults.

The amount of movement in faults can be completely ascertained only by the aid of independent and accidental phenomena. In homogeneous rock masses (leaving out of consideration fault scarps, fault gulches, and other topographical phenomena, and treating the faulted mass as a solid without boundaries) the amount of movement can not be ascertained or even approximately estimated. The existence of a movement can be determined by the records left on the slipping surface or surfaces in the shape of ground-up rock or fault breccia, in polished and striated rock faces, and so on. It is certain, however, that the amount of friction as displayed by trituration and polishing is not necessarily proportionate to

the amount of movement, since faults with slight displacement are often accompanied by zones showing profound trituration, while others of far greater movement show to a much less degree the effects of friction. The friction in each case seems to depend upon the angle of the chief stress to the sliding plane, rather than on the amount of movement along this plane. In heterogeneous rocks the amount of movement of a fault can ordinarily be estimated with more or less accuracy, the degree of closeness depending upon the nature of difference in the composition of the rock mass. In such heterogeneous rocks the amount and direction of a fault movement must be judged by any available phenomenon or phenomena. By far the commonest variations in rock masses which are constant enough to be reliable as data are in sedimentary beds, and therefore the commonest means of measuring a fault movement is the separation of the two parts of an originally continuous stratum. On this account it is easy to fall into the error of considering faults simply as dislocations of strata. In careful geological work, however, such as mining work must necessarily be, it is important to cultivate a more correct conception, and to regard sedimentary beds as phenomena accidentally associated with faulting, whose dislocation must be associated with all other available criteria, each one as valuable as the other, to determine the amount and direction of the total movement or displacement. Any fault, for example, in which the direction of movement is parallel with the plane of sedimentation will not cause any apparent displacement in a sedimentary bed, whatever may be the attitude of the fault plane in relation to the plane of the stratum; and this may be the case in faults having any conceivable attitude, since the sedimentary beds themselves may be folded so as to stand in every conceivable attitude with reference to any fixed plane, such as the earth's surface.

When the direction of movement in a fault lies at a slight angle to the plane of sedimentation, the apparent displacement of a stratum resulting from this fault will be only a slight part of the actual fault movement; and it is only when the direction of movement is perpendicular to the plane of sedimentation that the separation of the parts of the faulted stratum is an accurate measurement of the movement. Theoretically speaking, the chances are infinitely against any such coincidence, and in actual practice it is rare that the movement may be even approximately estimated in this

way. In mining geology it has been found that the most valuable criteria for measuring faults are, besides sedimentary beds: igneous bodies, such as dikes; bodies of ore; striæ on the fault plane, showing the direction of movement; and the composition of the fault breccia, which may show, in some degree, the amount of movement. By taking several of these criteria together it is often possible actually to ascertain the movement of a fault.

It is sometimes possible to find out the amount and direction of movement immediately; but more often it must be indirectly calculated, and to do this it is important to have clearly in mind the nature and value of some of the principal functions of a fault movement, and to have specific terms by which to designate them. The terms already in use are of a rather vague and general character, resulting from the usual conception of a fault as a dislocation of strata. The four terms generally employed are *displacement*, *throw*, *heave*, and *offset*. The words *displacement* and *throw* are used interchangeably, and commonly refer to the separation of beds by a fault as seen in a vertical section. Each of these terms is used by some to indicate the distance along the fault plane between the broken ends of the bed as seen in the section, and sometimes the perpendicular distance between the parts of such beds, projected if necessary. There is no agreement, however, which definitely assigns the terms to separate measurements, and indeed it is very common for a writer to use the terms interchangeably for one or the other function. *Heave* and *offset* are also used interchangeably, and are usually held to signify the perpendicular distance measured on a horizontal plane, such as the earth's surface, between portions—projected if necessary—of a bed separated by a fault.

In mining work it is generally necessary to differentiate clearly the different functions of a fault movement, and I have adopted the following terms descriptive of the most important of these. These terms include nothing very novel in the way of nomenclature, but are intended simply to affix definite names to definite things.

Dislocation and *displacement* are general terms, applicable to any part or the whole of a fault movement. Each of the functions defined below, and to which specific names are given, may be called simply a dislocation or displacement.

Total displacement is the distance which two points originally adjacent are separated by the fault movement. The line connecting these two

points lies in the fault plane in all straight faults. It is occasionally possible to determine the total displacement directly by such criteria as the separation of the parts of an ore body, the intersection of a given dike with a given stratum when found on both sides of the fault, and in other ways; but ordinarily it can only be calculated or approximately estimated from some of its more easily measured functions.

The *lateral separation* is the perpendicular or shortest distance between the two parts of any continuous zonal body, such as a sedimentary bed, which has been separated by a fault, the distance being measured along the fault plane. The lateral separation may be measured in a vertical, horizontal, or oblique line, according to the attitude of the bodies between which it is measured, and in any fault it may vary from zero to the total displacement. In the case of dikes cutting sedimentary beds, of marked unconformity, of abrupt folds, and so on, it may be possible to measure two or more lateral separations in a single fault. In this case, and in a number of others which are possible, the total displacement may often be calculated from the lateral separation, since the latter is always the side of a right triangle of which the former is the hypotenuse.

The *perpendicular separation* is the perpendicular distance between corresponding planes in the two parts of any single body available as criterion (such as a sedimentary bed), when this body has been separated by a fault, the planes on each side of the fault being projected for the purpose of measuring, if necessary. The perpendicular separation thus has a certain relation to the lateral separation; for it constitutes the side of a right triangle, the hypotenuse of which is the lateral separation, except in the possible case where the perpendicular and lateral separations coincide.

This mathematical relation makes it often possible to estimate the lateral separation from the perpendicular separation, and from the latter the total displacement. Of these three functions, the perpendicular separation is most easy of measurement, and its value may vary from zero to the full amount of lateral separation. The lateral separation is easier to ascertain than the total displacement, and its value may vary from zero to the total displacement.

The measurements which have been defined have no constant direction, since they refer to fault movements which are capable of infinite variation. In general geological work, however, it is often only possible

to measure fault movements along certain arbitrary planes. The most valuable of these planes are the earth's surface, which may be considered a horizontal plane, and vertical sections, into which available data are put, with the gaps in the chain of information often theoretically filled out. In such cases, where some dislocation is evident, but the information is so meager that it is not possible to know the fault so accurately as to estimate even approximately its total displacement or lateral or perpendicular separation, it is necessary to employ specific terms to designate the known or estimated dislocations, although the relations of these dislocations to the total displacement may be unknown. For this purpose the terms *heave* or *offset*, *throw*, and *vertical separation* may be used. The terms *throw* and *vertical separation* are applied to the dislocations of a fault as seen in a vertical section; the terms *heave* and *offset*, to the dislocation as seen in a horizontal section, such as the earth's surface may be considered.

The *throw* may be defined as the distance between the two parts of any body available as a criterion (such as a sedimentary bed), when these parts have been separated by a fault, the distance being measured along the fault plane as shown in a vertical section.

The *vertical separation* is the perpendicular distance between the intersection of the two parts of any body available as a criterion, such as a sedimentary bed, with the plane of a vertical section, the lines of intersection being projected, if necessary, for the purpose of measurement. In perpendicular faults the vertical separation is identical with the throw. In all others it is less than the throw, but sustains a certain relationship to it, being one side of a right triangle of which the throw is the hypotenuse. Thus the vertical separation may vary from zero to the full amount of the throw. The throw is always a part of the total displacement, although with no definite relationship to it, and varies from zero to the full total displacement.

The terms *heave* and *offset* may be used interchangeably to designate the perpendicular distance between the intersections of corresponding planes in the two parts of any body available as a criterion, such as a sedimentary bed, with a horizontal plane, such as the earth's surface may be considered. Like the throw, the heave or offset is a part of the total displacement, but it has no definite relationship to it.

To sum up, there are six terms proposed to designate different parts of a fault movement, each term applying to a measurement which varies in accuracy and proximity to the total displacement in proportion to the available amount of information. For general outline work, where accurate data are not obtainable, the terms *throw* and *vertical separation*, referring to the measurements of a fault at its intersection with a vertical plane, and the term *heave* or *offset*, indicating a measurement of a fault at its intersection with a horizontal plane, are adopted. The throw and offset are parts of the actual fault movement, but of unknown value, while the vertical displacement sustains a certain relationship to the throw. Where more complete data are obtainable, the terms *total displacement*, *lateral separation*, and *perpendicular separation* are adopted. The perpendicular separation sustains a certain relationship to the lateral separation, as the lateral separation does to the total displacement.

INDEX.

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[Monograph XXXI.]

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49. Latitudes and Longitudes of Certain Points in Missouri, Kansas, and New Mexico, by Robert Simpson Woodward. 1889. 8°. 133 pp. Price 15 cents.

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86. Correlation Papers—Archean and Algonkian, by C. R. Van Hise. 1892. 8°. 549 pp. 12 pl. Price 25 cents.

87. A Synopsis of American Fossil. Brachiopoda, including Bibliography and Synonymy, by Charles Schuchert. 1897. 8°. 464 pp. Price 30 cents.

88. The Cretaceous Foraminifera of New Jersey, by Rufus Mather Bagg, Jr. 1898. 8°. 89 pp. 6 pl. Price 10 cents.

89. Some Lava Flows of the Western Slope of the Sierra Nevada, California, by F. Leslie Ransome. 1898. 8°. 74 pp. 11 pl. Price 15 cents.

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99. Record of North American Geology for 1891, by Nelson Horatio Darton. 1892. 8°. 73 pp. Price 10 cents.

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103. High Temperature Work in Igneous Fusion and Ebullition, chiefly in Relation to Pressure, by Carl Barus. 1893. 8°. 57 pp. 9 pl. Price 10 cents.

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127. Catalogue and Index of Contributions to North American Geology, 1732-1891, by Nelson Horatio Darton. 1896. 8°. 1045 pp. Price 60 cents.

128. The Bear River Formation and its Characteristic Fauna, by Charles A. White. 1895. 8°. 108 pp. 11 pl. Price 15 cents.

129. Earthquakes in California in 1894, by Charles D. Perrine. 1895. 8°. 25 pp. Price 5 cents.

130. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for 1892 and 1893, by Fred Boughton Weeks. 1896. 8°. 210 pp. Price 20 cents.

131. Report of Progress of the Division of Hydrography for the Calendar Years 1893 and 1894, by Frederick Haynes Newell, Topographer in Charge. 1895. 8°. 126 pp. Price 15 cents.

132. The Disseminated Lead Ores of Southeastern Missouri, by Arthur Winslow. 1896. 8°. 31 pp. Price 5 cents.

133. Contributions to the Cretaceous Paleontology of the Pacific Coast: The Fauna of the Knoxville Beds, by T. W. Stanton. 1895. 8°. 132 pp. 20 pl. Price 15 cents.

134. The Cambrian Rocks of Pennsylvania, by Charles Doolittle Walcott. 1896. 8°. 43 pp. 15 pl. Price 5 cents.

135. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for the Year 1894, by F. B. Weeks. 1896. 8°. 141 pp. Price 15 cents.

136. Volcanic Rocks of South Mountain, Pennsylvania, by Florence Bascom. 1896. 8°. 124 pp. 28 pl. Price 15 cents.

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146. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for the Year 1895, by F. B. Weeks. 1896. 8°. 130 pp. Price 15 cents.
147. Earthquakes in California in 1895, by Charles D. Perrine, Assistant Astronomer in Charge of Earthquake Observations at the Lick Observatory. 1896. 8°. 23 pp. Price 5 cents.
148. Analyses of Rocks, with a Chapter on Analytical Methods, Laboratory of the United States Geological Survey, 1880 to 1896, by F. W. Clarke and W. F. Hillebrand. 1897. 8°. 306 pp. Price 20 cents.
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150. The Educational Series of Rock Specimens collected and distributed by the United States Geological Survey, by Joseph Silas Diller. 1898. 8°. 398 pp. 47 pl. Price 25 cents.
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156. Bibliography and Index of North American Geology, Paleontology, Petrology, and Mineralogy for the Year 1897, by Fred Boughton Weeks. 1898. 8°. 130 pp. Price 15 cents.

In preparation:

157. The Gneisses, Gabbro-Schists, and Associated Rocks of Southeastern Minnesota, by C. W. Hall.
158. The Moraines of South Dakota and their Attendant Deposits, by J. E. Todd.
159. The Geology of Eastern Berkshire County, Massachusetts, by B. K. Emerson.

WATER-SUPPLY AND IRRIGATION PAPERS.

By act of Congress approved June 11, 1896, the following provision was made:

"*Provided*, That hereafter the reports of the Geological Survey in relation to the gauging of streams and to the methods of utilizing the water resources may be prin ed in octavo form, not to exceed one hundred pages in length and five thousand copies in number; one thousand copies of which shall be for the official use of the Geological Survey, one thousand five hundred copies shall be delivered to the Senate, and two thousand five hundred copies shall be delivered to the House of Representatives, for distribution."

Under this law the following papers have been issued:

1. Pumping Water for Irrigation, by Herbert M. Wilson. 1896. 8°. 57 pp. 9 pl.
2. Irrigation near Phœnix, Arizona, by Arthur P. Davis. 1897. 8°. 97 pp. 31 pl.
3. Sewage Irrigation, by George W. Rafter. 1897. 8°. 100 pp. 4 pl.
4. A Reconnoissance in Southeastern Washington, by Israel Cook Russell. 1897. 8°. 96 pp. 7 pl.
5. Irrigation Practice on the Great Plains, by Elias Branson Cowgill. 1897. 8°. 39 pp. 12 pl.
6. Underground Waters of Southwestern Kansas, by Erasmus Haworth. 1897. 8°. 65 pp. 12 pl.
7. Seepage Waters of Northern Utah, by Samuel Fortier. 1897. 8°. 50 pp. 3 pl.
8. Windmills for Irrigation, by Edward Charles Murphy. 1897. 8°. 49 pp. 8 pl.
9. Irrigation near Greeley, Colorado, by David Boyd. 1897. 8°. 90 pp. 21 pl.
10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker. 1898. 8°. 51 pp. 11 pl.
11. River Heights for 1896, by Arthur P. Davis. 1897. 8°. 100 pp.
12. Water Resources of Southeastern Nebraska, by Nelson H. Darton. 1898. 8°. 55 pp. 21 pl.
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15. Operations at River Stations, 1897, Part I. 1898. 8°. 100 pp.
16. Operations at River Stations, 1897, Part II. 1898. 8°. 101–200 pp.
17. Irrigation near Bakersfield, California, by C. E. Grunsky. 1898. 8°. 96 pp. 16 pl.
18. Irrigation near Fresno, California, by C. E. Grunsky. 1898. 8°. 94 pp. 14 pl.

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19. Irrigation near Merced, California, by C. E. Grunsky.
20. Experiments with Windmills, by T. O. Perry.
21. Wells of Indiana, by Frank Leverett.
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24. Water Resources of the State of New York, Part I, by George W. Rafter.

TOPOGRAPHIC MAP OF THE UNITED STATES.

When, in 1882, the Geological Survey was directed by law to make a geologic map of the United States there was in existence no suitable topographic map to serve as a base for the geologic map. The preparation of such a topographic map was therefore immediately begun. About one-fifth of the area of the country, excluding Alaska, has now been thus mapped. The map is published in atlas sheets, each sheet representing a small quadrangular district, as explained under the following heading. The separate sheets are sold at 5 cents each when fewer than 100 copies are purchased, but when they are ordered in lots of 100 or more copies, whether of the same sheet or of different sheets, the price is 2 cents each. The mapped areas are widely scattered, nearly every State being represented. More than 800 sheets have been engraved and printed; they are tabulated by States in the Survey's "List of Publications," a pamphlet which may be had on application.

The map sheets represent a great variety of topographic features, and with the aid of descriptive text they can be used to illustrate topographic forms. This has led to the projection of an educational series of topographic folios, for use wherever geography is taught in high schools, academies, and colleges. Of this series the first folio has been issued, viz:

1. Physiographic types, by Henry Gannett, 1898, folio, consisting of the following sheets and 4 pages of descriptive text: Fargo (N. Dak.-Minn.), a region in youth; Charleston (W.Va.), a region in maturity; Caldwell (Kans.), a region in old age; Palmyra (Va.), a rejuvenated region; Mount Shasta, (Cal.), a young volcanic mountain; Eagle (Wis.), moraines; Sun Prairie (Wis.), drumlins; Donaldsonville (La.), river flood plains; Boothbay (Me.), a fiord coast; Atlantic City (N. J.), a barrier-beach coast.

GEOLOGIC ATLAS OF THE UNITED STATES.

The Geologic Atlas of the United States is the final form of publication of the topographic and geologic maps. The atlas is issued in parts, progressively as the surveys are extended, and is designed ultimately to cover the entire country.

Under the plan adopted the entire area of the country is divided into small rectangular districts (designated *quadrangles*), bounded by certain meridians and parallels. The unit of survey is also the unit of publication, and the maps and descriptions of each rectangular district are issued as a folio of the Geologic Atlas.

Each folio contains topographic, geologic, economic, and structural maps, together with textual descriptions and explanations, and is designated by the name of a principal town or of a prominent natural feature within the district.

Two forms of issue have been adopted, a "library edition" and a "field edition." In both the sheets are bound between heavy paper covers, but the library copies are permanently bound, while the sheets and covers of the field copies are only temporarily wired together.

Under the law a copy of each folio is sent to certain public libraries and educational institutions. The remainder are sold at 25 cents each, except such as contain an unusual amount of matter, which are priced accordingly. Prepayment is obligatory. The folios ready for distribution are listed below.

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price, in cents.
1	Livingston	Montana	110°–111°	45°–46°	3,354	25
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5	Sacramento	California	121°–121° 30′	38° 30′–39°	932	25
6	Chattanooga	Tennessee	85°–85° 30′	35°–35° 30′	975	25
7	Pikes Peak (out of stock)	Colorado	105°–105° 30′	38° 30′–39°	932	25
8	Sewanee	Tennessee	85° 30′–86°	35°–35° 30′	975	25
9	Anthracite-Crested Butte	Colorado	106° 45′–107° 15′	38° 45′–39°	465	50
10	Harpers Ferry	Virginia West Virginia Maryland	77° 30′–78°	39°–39° 30′	925	25
11	Jackson	California	120° 30′–121°	38°–38° 30′	938	25
12	Estillville	Virginia Kentucky Tennessee	82° 30′–83°	36° 30′–37°	957	25
13	Fredericksburg	Maryland Virginia	77°–77° 30′	38°–38° 30′	938	25
14	Staunton	Virginia West Virginia	79°–79° 30′	38°–38° 30′	938	25
15	Lassen Peak	California	121°–122°	40°–41°	3,634	25
16	Knoxville	Tennessee North Carolina	83° 30′–84°	35° 30′–36°	925	25

No.	Name of sheet.	State.	Limiting meridians.	Limiting parallels.	Area, in square miles.	Price in cents.
17	Marysville	California	121° 30′–122°	39°–39° 30′	925	25
18	Smartsville	California	121°–121° 30′	39°–39° 30′	925	25
19	Stevenson	Alabama Georgia Tennessee	85° 30′–86°	34° 30′–35°	980	25
20	Cleveland	Tennessee	84° 30′–85°	35°–35° 30′	975	25
21	Pikeville	Tennessee	85°–85° 30′	35° 30′–36°	969	25
22	McMinnville	Tennessee	85° 30′–86°	35° 30′–36°	969	25
23	Nomini	Maryland Virginia	76° 30′–77°	38°–38° 30′	938	25
24	Three Forks	Montana	111°–112°	45°–46°	3,354	50
25	Loudon	Tennessee	84°–81° 30′	35° 30′–36°	969	25
26	Pocahontas	Virginia West Virginia	81°–81° 30′	37°–37° 30′	951	25
27	Morristown	Tennessee	83°–83° 30′	36°–36° 30′	963	25
28	Piedmont	Virginia Maryland West Virginia	79°–79° 30′	39°–39° 30′	925	25
29	Nevada City: Nevada City Grass Valley Banner Hill	California	121° 00′ 25″–121° 03′ 45″ 121° 01′ 35″–121° 05′ 04″ 120° 57′ 05″–121° 00′ 25″	39° 13′ 50″–39° 17′ 16″ 39° 10′ 22″–39° 13′ 50″ 39° 13′ 50″–39° 17′ 16″	11.65 12.09 11.65	50
30	Yellowstone National Park: Gallatin Canyon Shoshone Lake	Wyoming	110°–111°	44°–45°	3,412	75
31	Pyramid Peak	California	120°–120° 30′	38° 30′–39°	932	25
32	Franklin	Virginia West Virginia	79°–79° 30′	38° 30′–39°	932	25
33	Briceville	Tennessee	84°–84° 30′	36°–36° 30′	963	25
34	Buckhannon	West Virginia	80°–80° 30′	38° 30′–39°	932	25
35	Gadsden	Alabama	86°–86° 30′	34°–34° 30′	986	25
36	Pueblo	Colorado	104° 30′–105°	38°–38° 30′	938	50
37	Downieville	California	120° 30′–121°	39° 30′–40°	919	25
39	Truckee	California	120°–120° 30′	39°–39° 30′	925	25
40	Wartburg	Tennessee	84° 30′–85°	36°–36° 30′	963	25
41	Sonora	California	120°–120° 30′	37° 30′–38°	944	25
42	Nueces	Texas	100°–100° 30′	29° 30′–30°	1,035	25
43	Bidwell Bar	California	121°–121° 30′	39° 30′–40°	918	25
44	Tazewell	Virginia West Virginia	81° 30′–82°	37°–37° 30′	950	25
45	Boise	Idaho	116°–116° 30′	43° 30′–44°	864	25

STATISTICAL PAPERS.

Mineral Resources of the United States [1882], by Albert Williams, jr. 1883. 8°. xvii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1883 and 1884, by Albert Williams, jr. 1885. 8°. xiv, 1016 pp. Price 60 cents.

Mineral Resources of the United States, 1885. Division of Mining Statistics and Technology. 1886. 8°. vii, 576 pp. Price 40 cents.

Mineral Resources of the United States, 1886, by David T. Day. 1887. 8°. viii, 813 pp. Price 50 cents.

Mineral Resources of the United States, 1887, by David T. Day. 1888. 8°. vii, 832 pp. Price 50 cents.

Mineral Resources of the United States, 1888, by David T. Day. 1890. 8°. vii, 652 pp. Price 50 cents.

Mineral Resources of the United States, 1889 and 1890, by David T. Day. 1892. 8°. viii, 671 pp. Price 50 cents.

Mineral Resources of the United States, 1891, by David T. Day. 1893. 8°. vii, 630 pp. Price 50 cents.

Mineral Resources of the United States, 1892, by David T. Day. 1893. 8°. vii, 850 pp. Price 50 cents.

Mineral Resources of the United States, 1893, by David T. Day. 1894. 8°. viii, 810 pp. Price 50 cents.

On March 2, 1895, the following provision was included in an act of Congress:

"*Provided,* That hereafter the report of the mineral resources of the United States shall be issued as a part of the report of the Director of the Geological Survey."

In compliance with this legislation the following reports have been published:

Mineral Resources of the United States, 1894, David T. Day, Chief of Division. 1895. 8°. xv, 646 pp., 23 pl.; xix, 735 pp., 6 pl. Being Parts III and IV of the Sixteenth Annual Report.

Mineral Resources of the United States, 1895, David T. Day, Chief of Division. 1896. 8°. xxiii, 542 pp., 8 pl. and maps; iii, 543–1058 pp., 9–13 pl. Being Part III (in 2 vols.) of the Seventeenth Annual Report.

Mineral Resources of the United States, 1896, David T. Day, Chief of Division. 1897. 8°. xii, 642 pp., 1 pl.; 643–1400 pp. Being Part V (in 2 vols.) of the Eighteenth Annual Report.

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